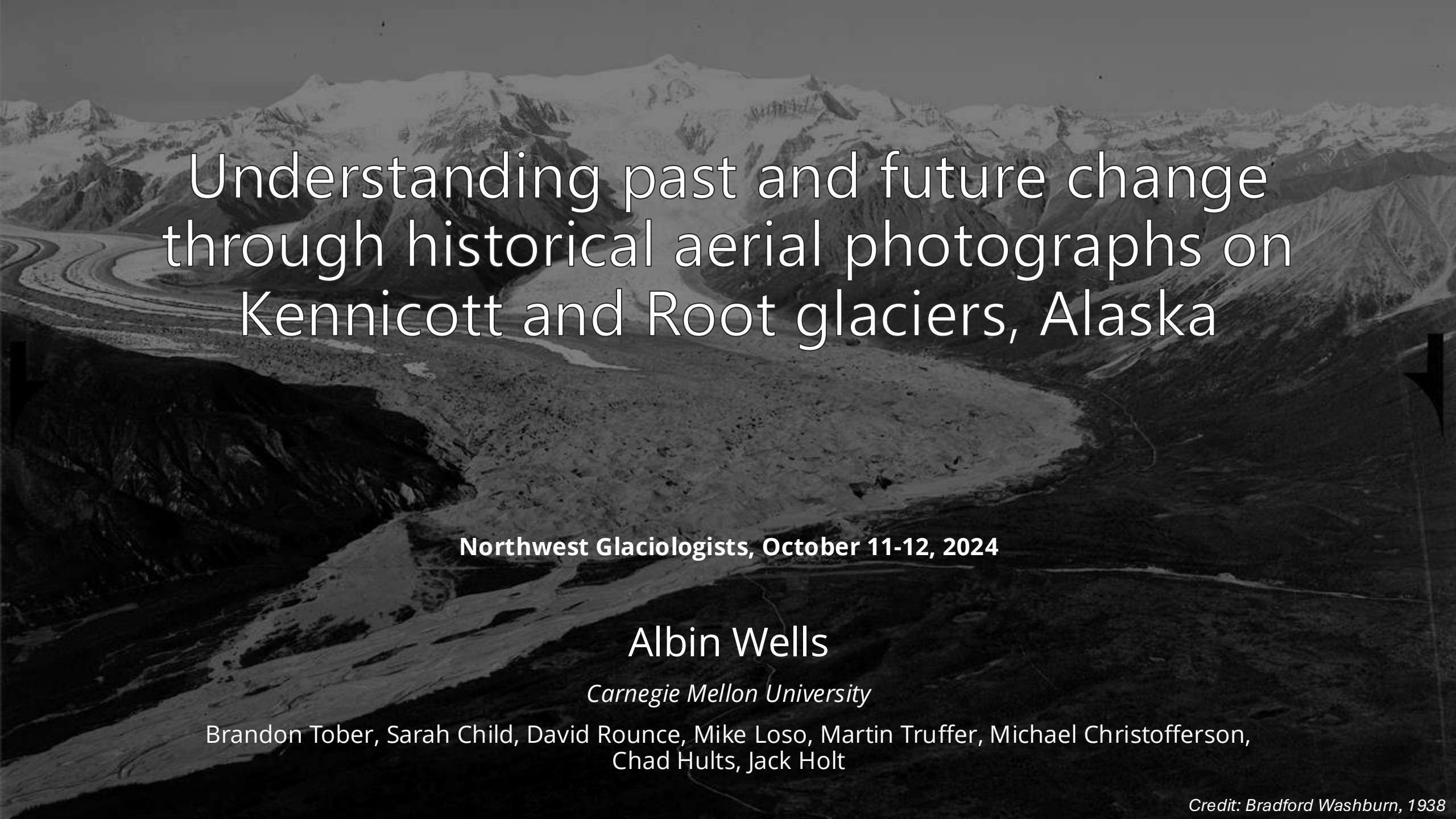


Understanding past and future change through historical aerial photographs on Kennicott and Root glaciers, Alaska

Northwest Glaciologists, October 11-12, 2024

Albin Wells

Carnegie Mellon University

Brandon Tober, Sarah Child, David Rounce, Mike Loso, Martin Truffer, Michael Christofferson, Chad Hults, Jack Holt

Credit: Bradford Washburn, 1938

Background

- Mountain glaciers are rapidly changing
- We can measure surface elevation change for all glaciers on Earth (e.g., Hugonnet et al. 2021, Jakob & Gourmelen 2023)
- The temporal span of these global observations (decades) is short relative to glacier response times (decades to centuries)
- ***We need to increase the temporal span of observations to understand processes affecting long-term glacier change and constrain glacier projections***

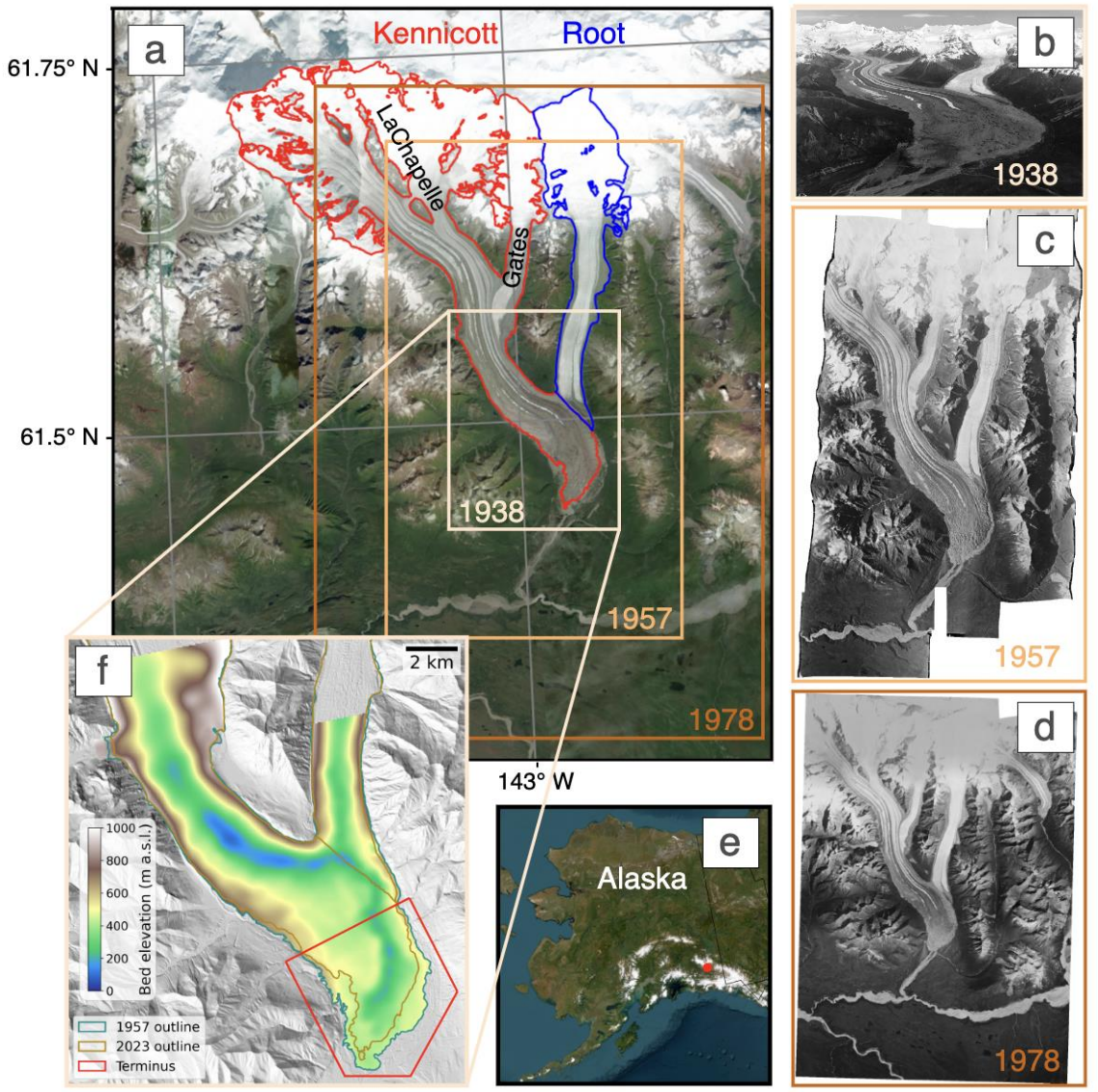
Key questions

- How can we use historical images to improve past, present, and future understanding of glaciers?
  - Case study on Kennicott and Root Glaciers in Alaska
- How do glacier dynamics and the climate contribute to retreat?
- How do historical observations affect projections from a glacier evolution model?

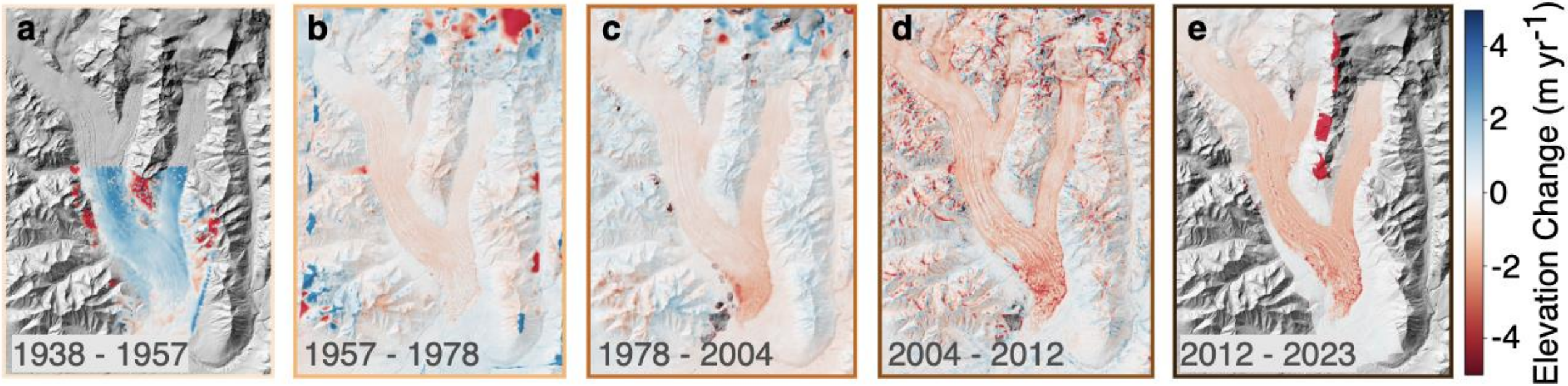
Kennicott and Root glacier are uniquely data-rich

- Historical DEMs (1938, 1957, 1962, 1978)
- Modern DEMs (2004, 2012, 2023)
- Bed data
- Velocity (Historical 1957-1962, ITS LIVE)
- Glacier outlines
- Climate data (1940-2100; ERA5, CMIP6)

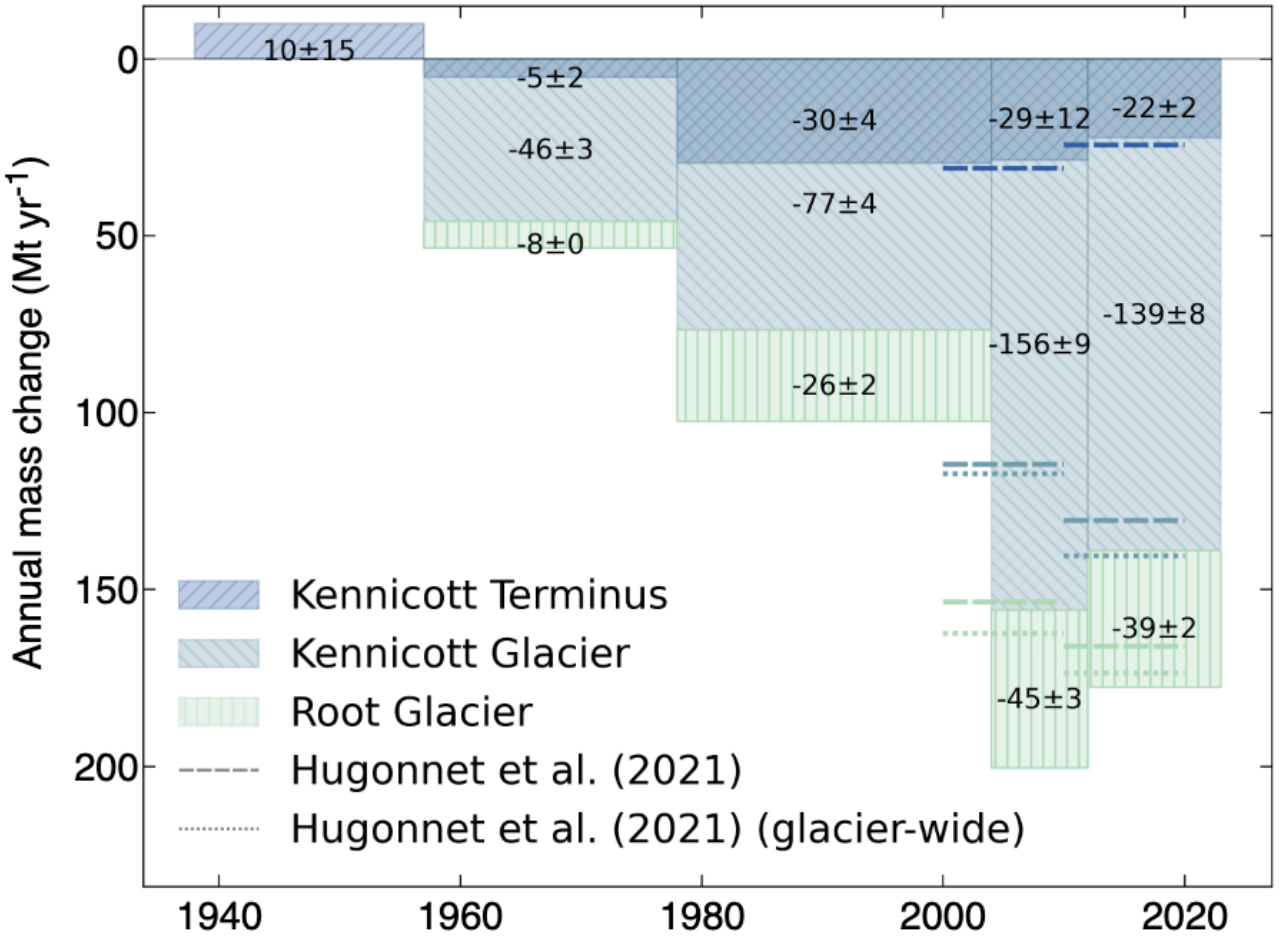
- ***Historical aerial photographs exist for much more of Alaska!***

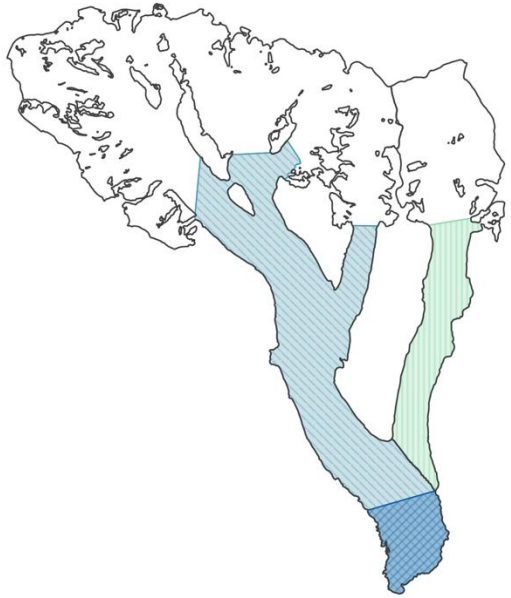


Historical record shows accelerating mass loss



Glacier-wide thinning precludes debris-covered terminus wastage





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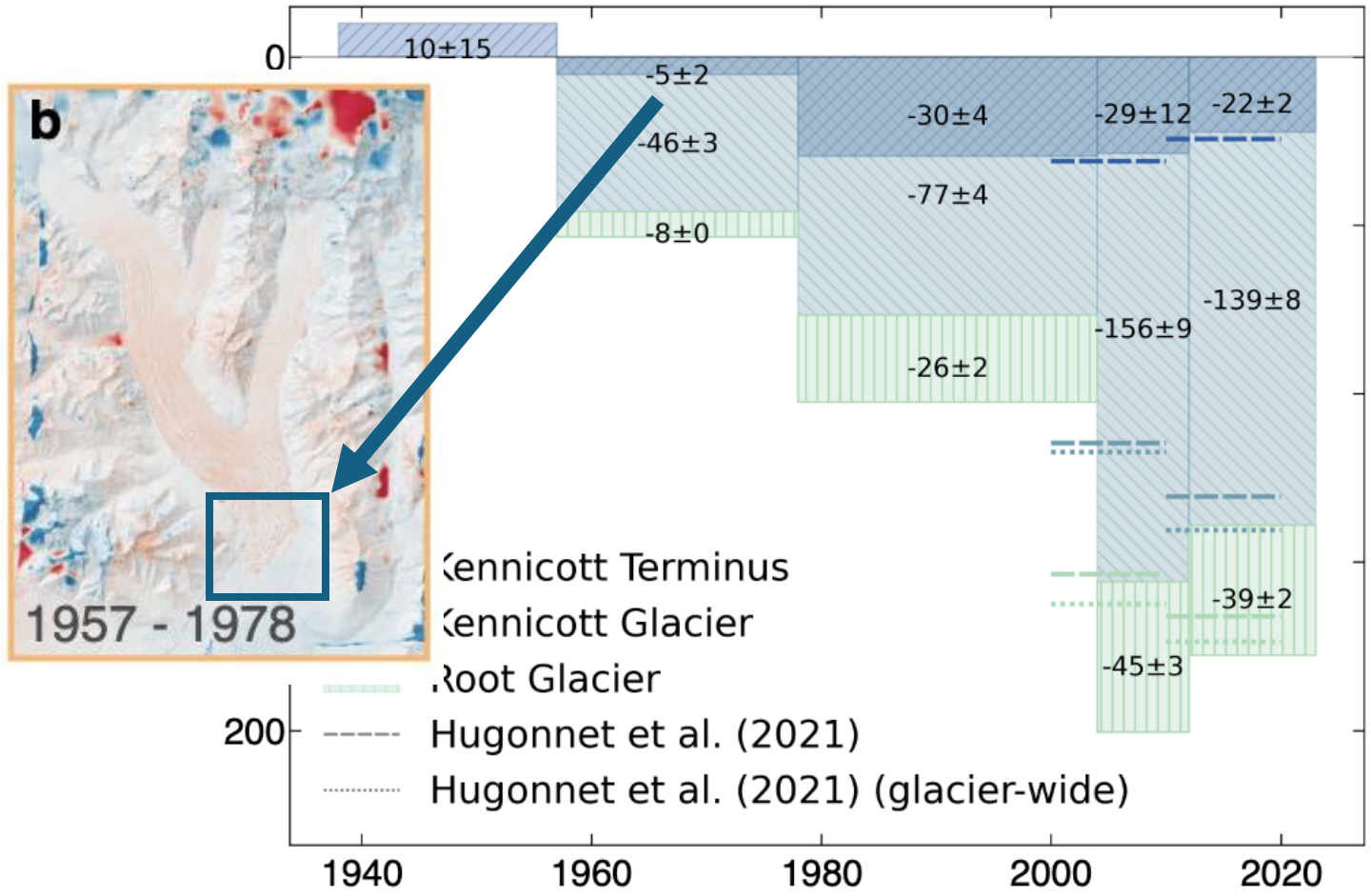

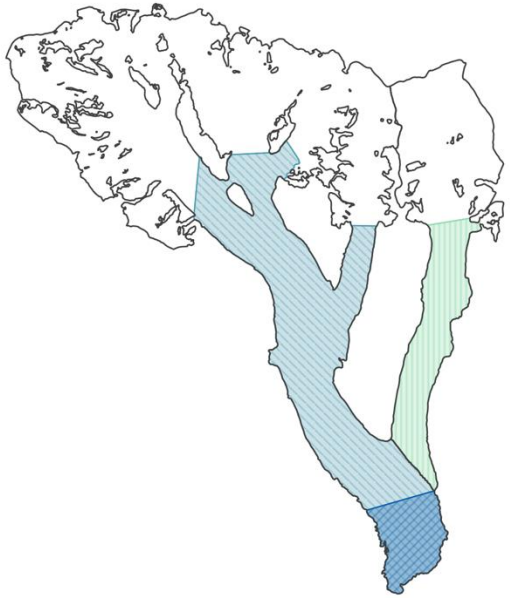

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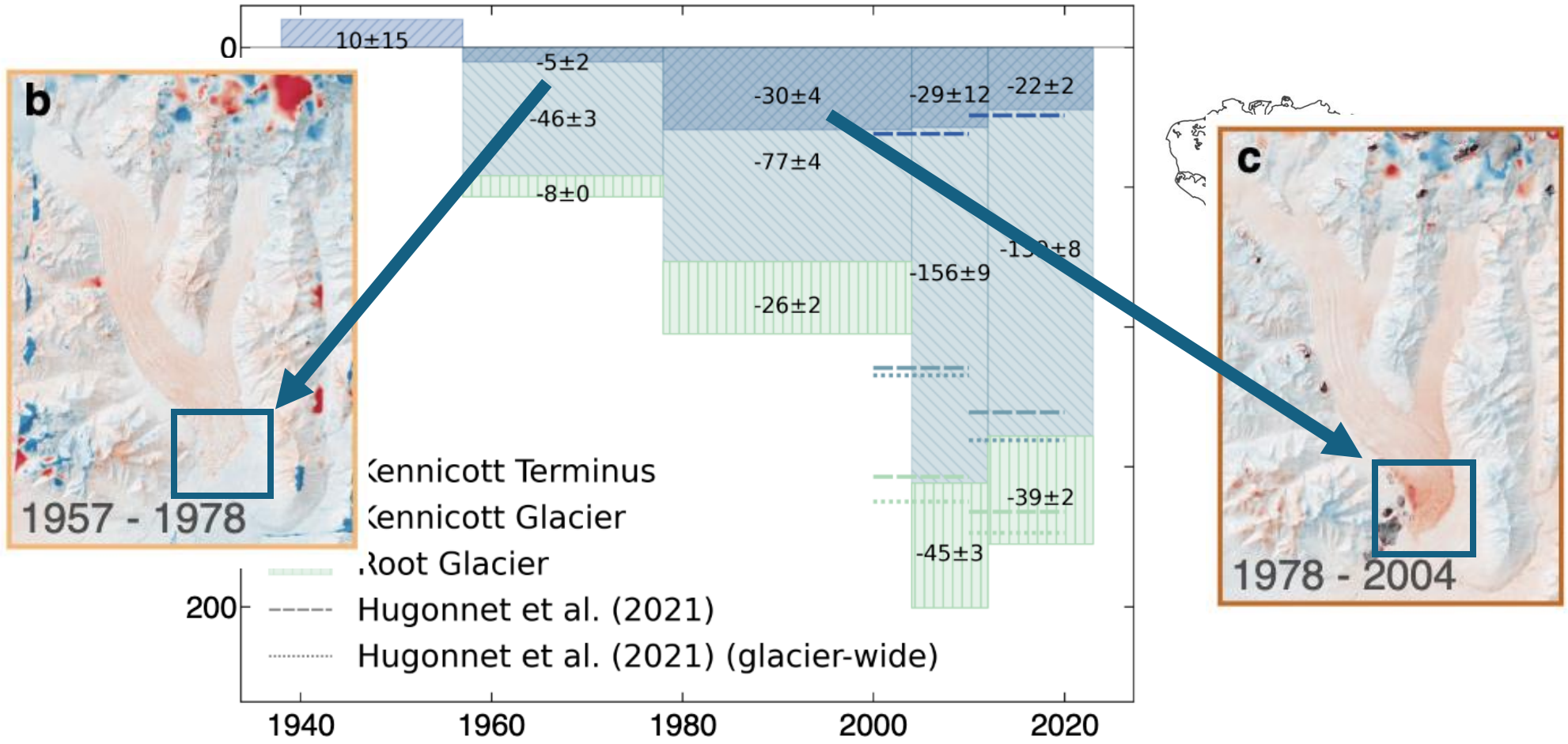
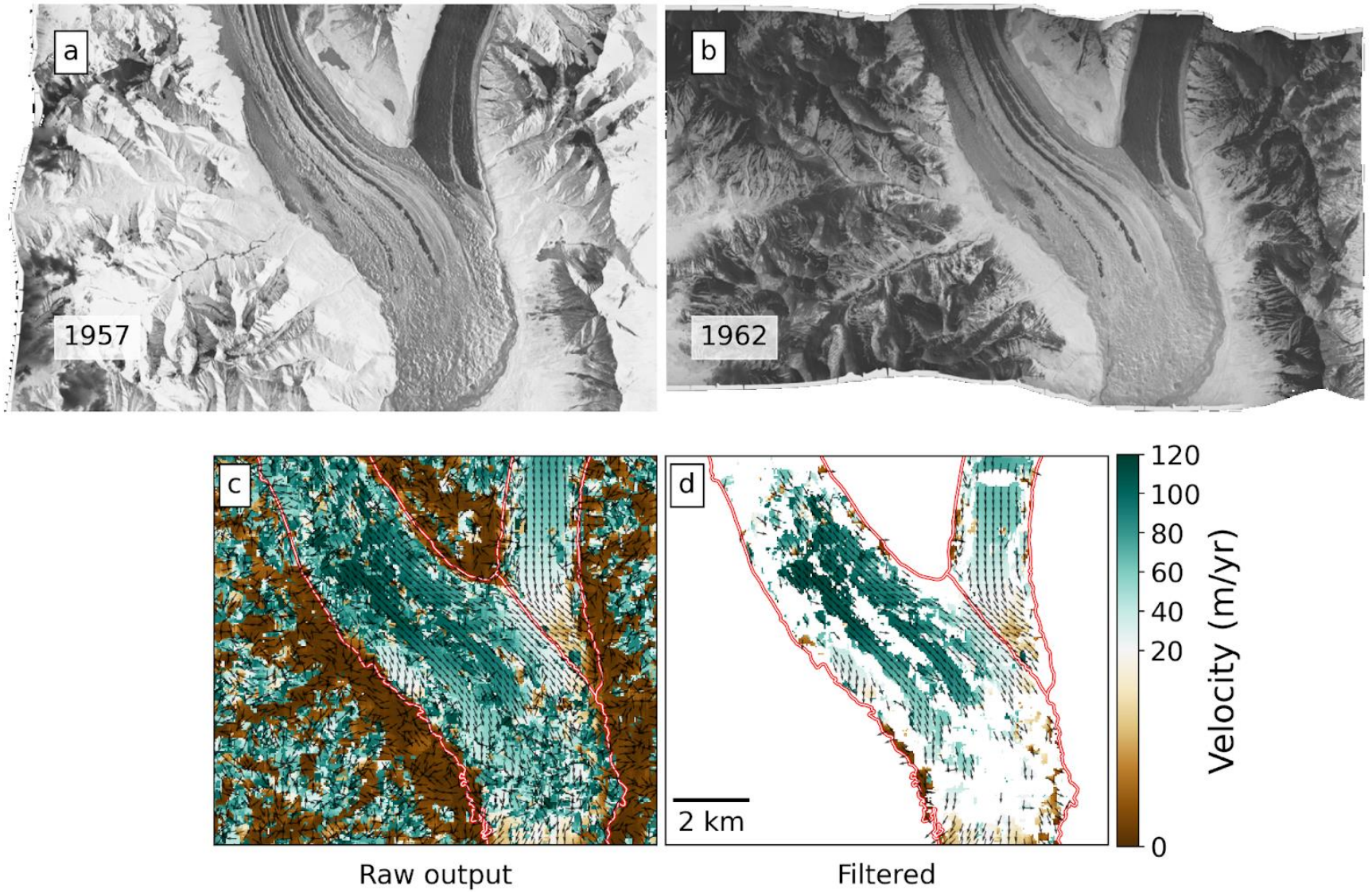
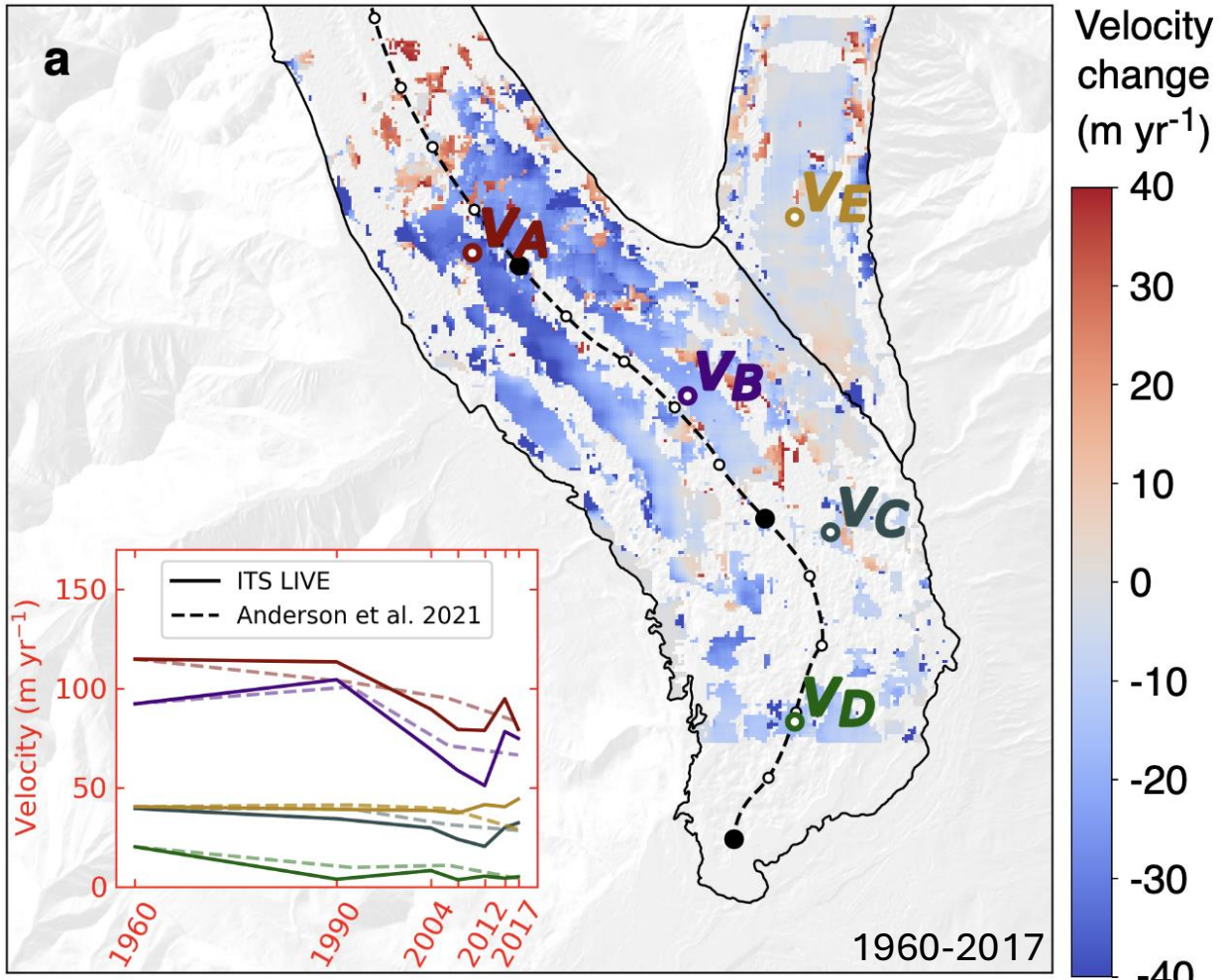


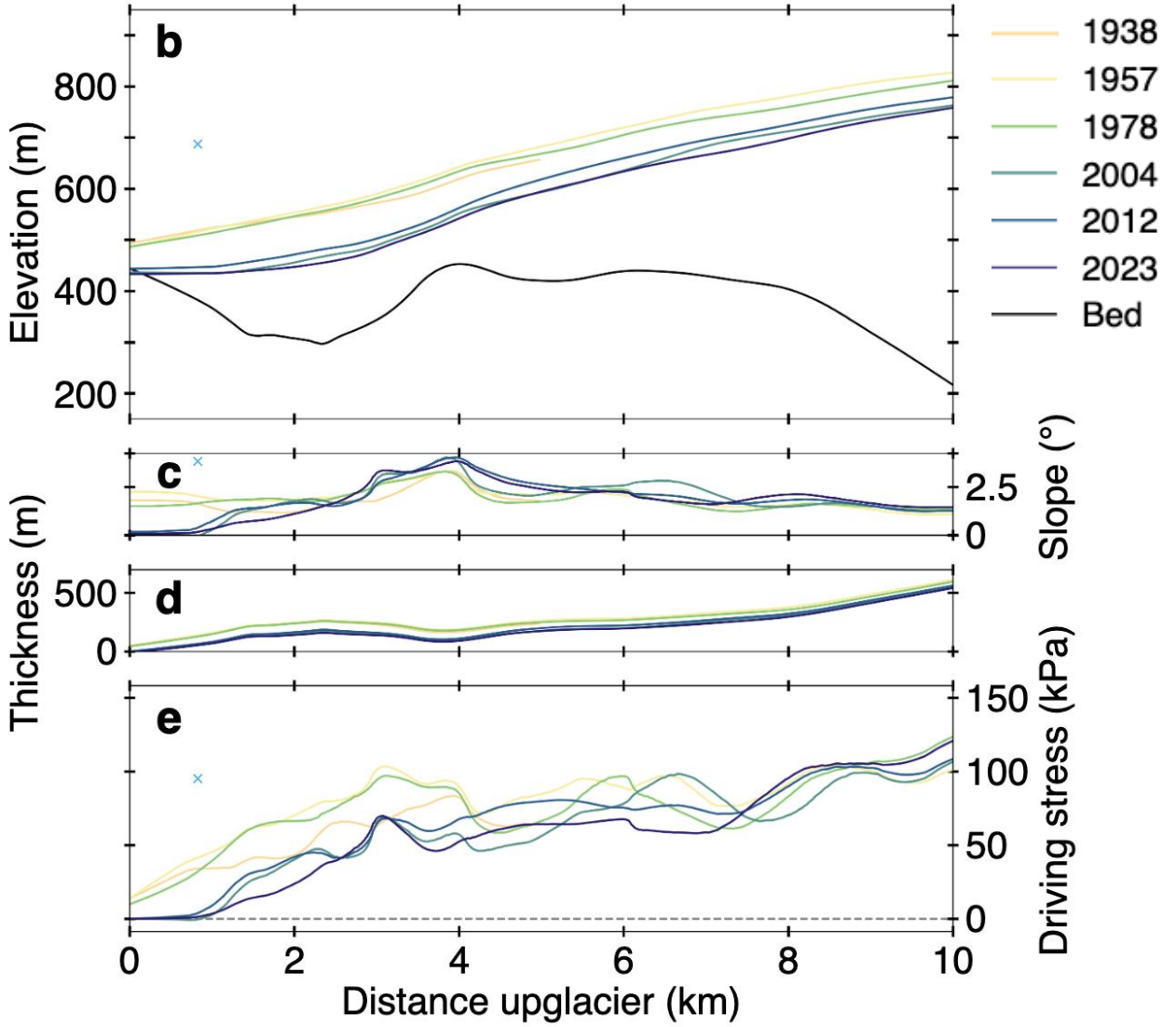
Historical photographs can also yield past velocity

- Feature-tracking of orthophotos with PyCorr software is effective on clean-ice over 5 years

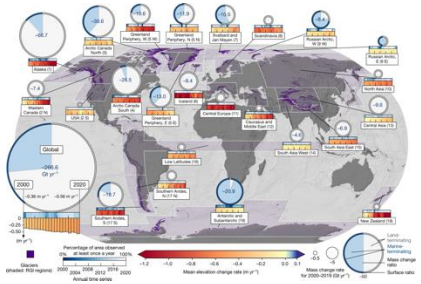


Substantial changes in glacier dynamics over time



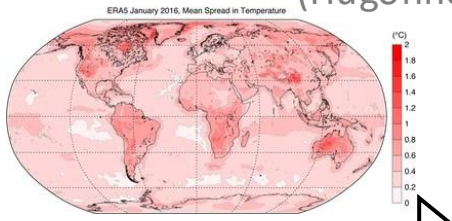


How do past observations affect projections?



2000 - 2020

(Hugonnet et al., 2021)

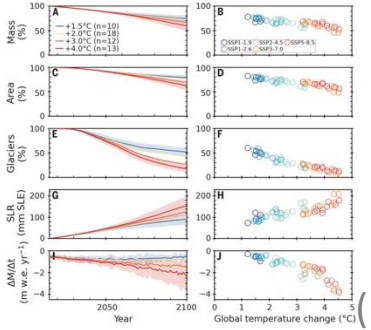


Climate data

(ERA5)

PyGEM

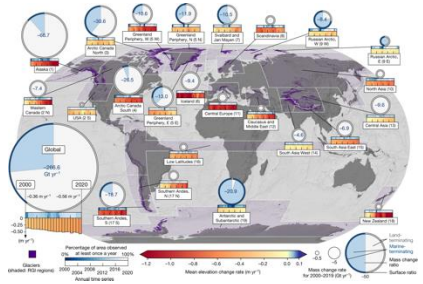
T_{bias} k_p ddf_{snow}



2020 - 2100

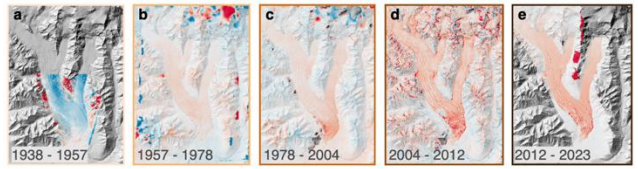
(Rounce et al., 2023)

How do past observations affect projections?

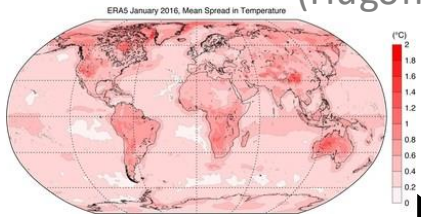


2000 - 2020

(Hugonnet et al., 2021)



1938 – 2023



Climate data

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PyGEM

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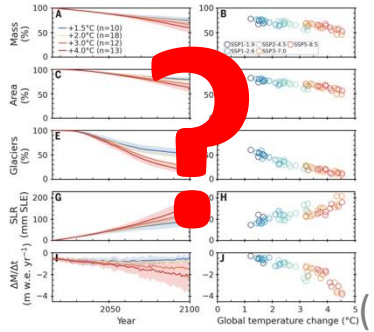
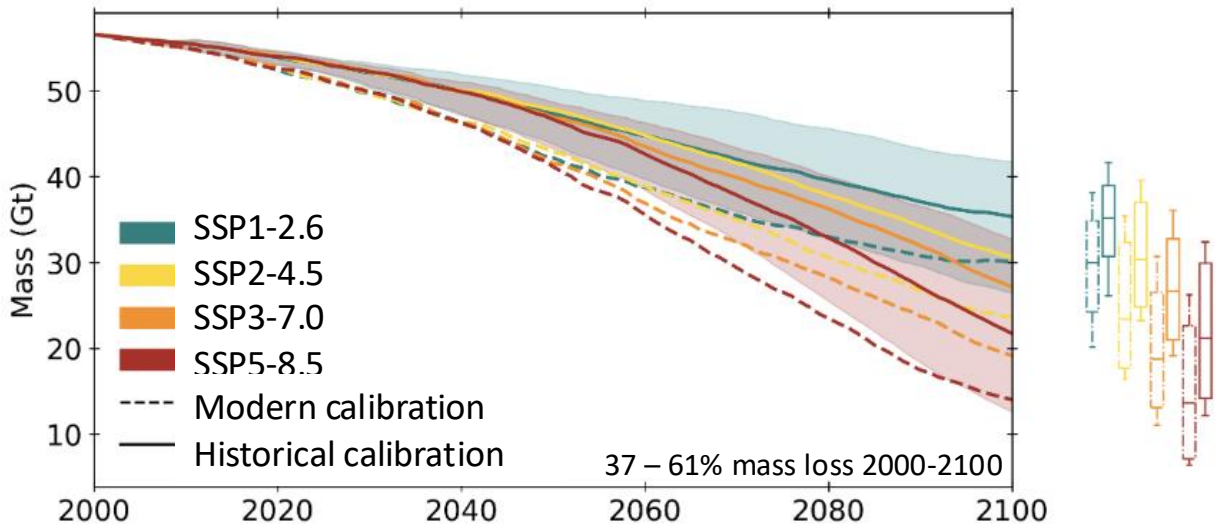


2020 - 2100

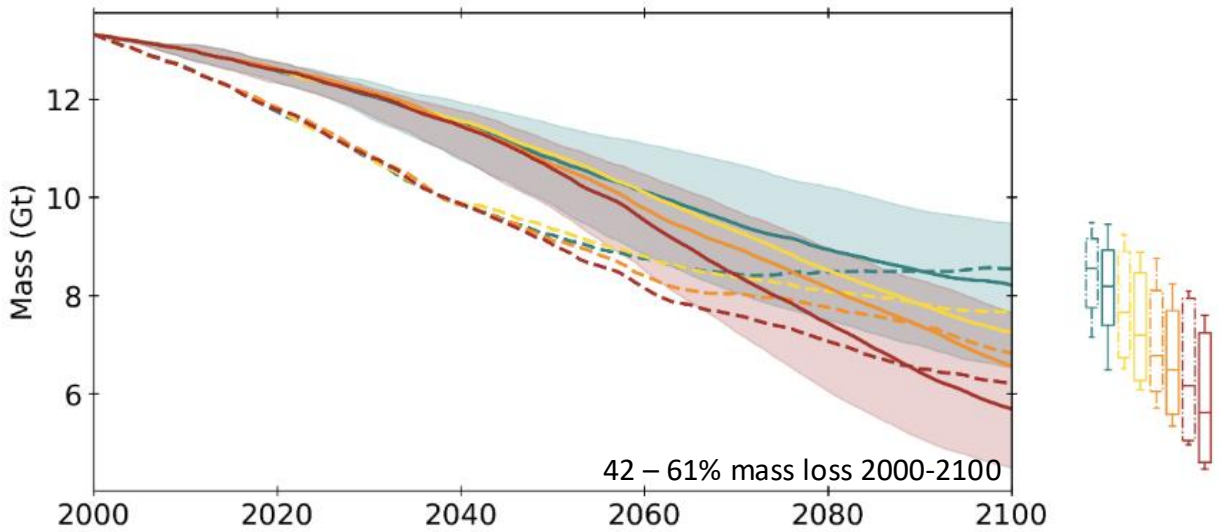
(Rounce et al., 2023)

Past observations constrains future mass loss

Kennicott Glacier



Root Glacier



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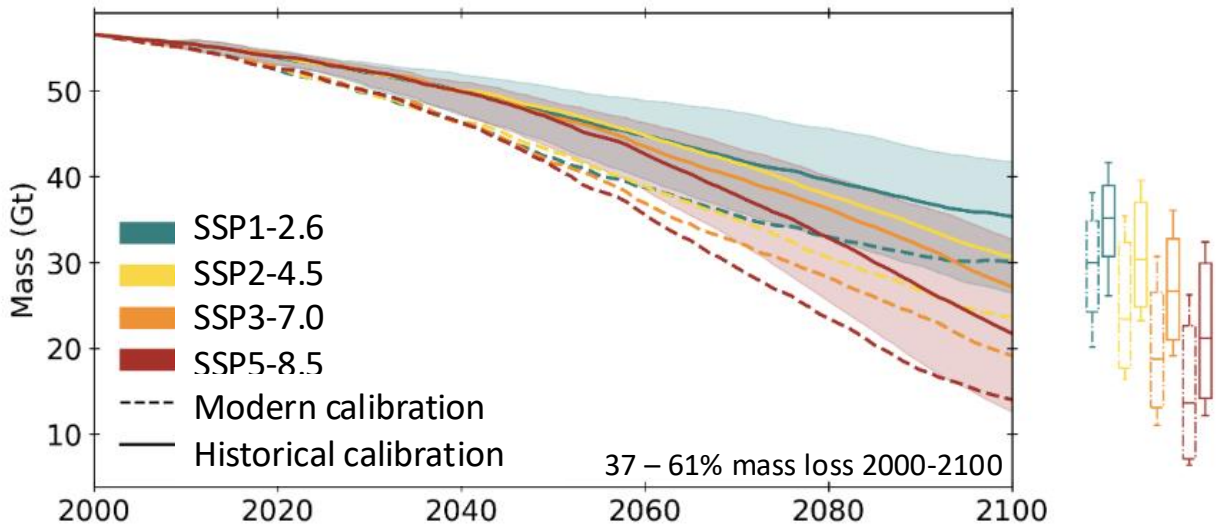
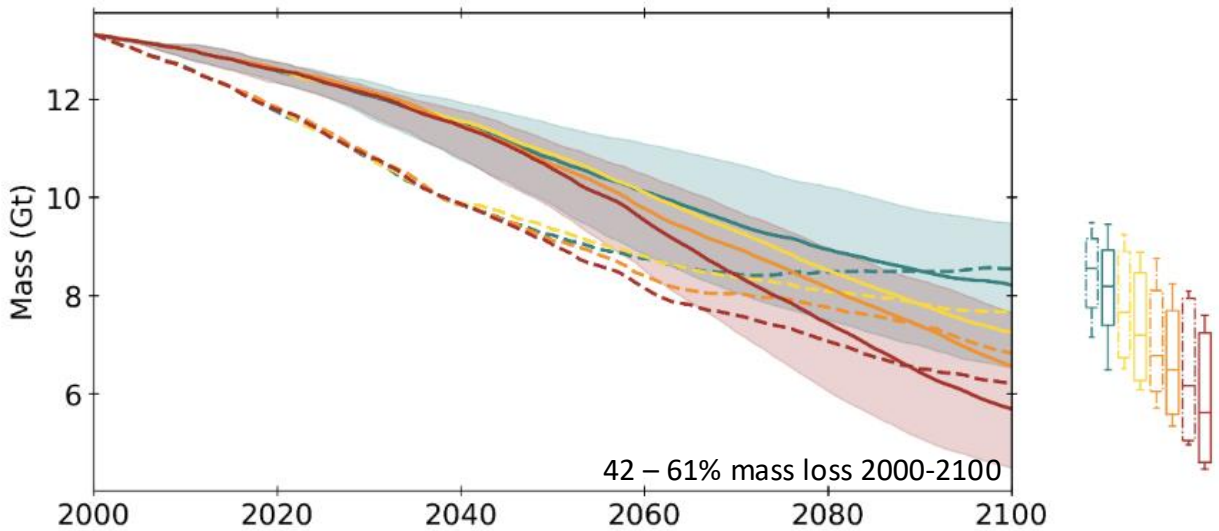


Improved model predicts 22% *less* mass loss by 2100

Root Glacier



Improved model predicts 7% *more* mass loss by 2100

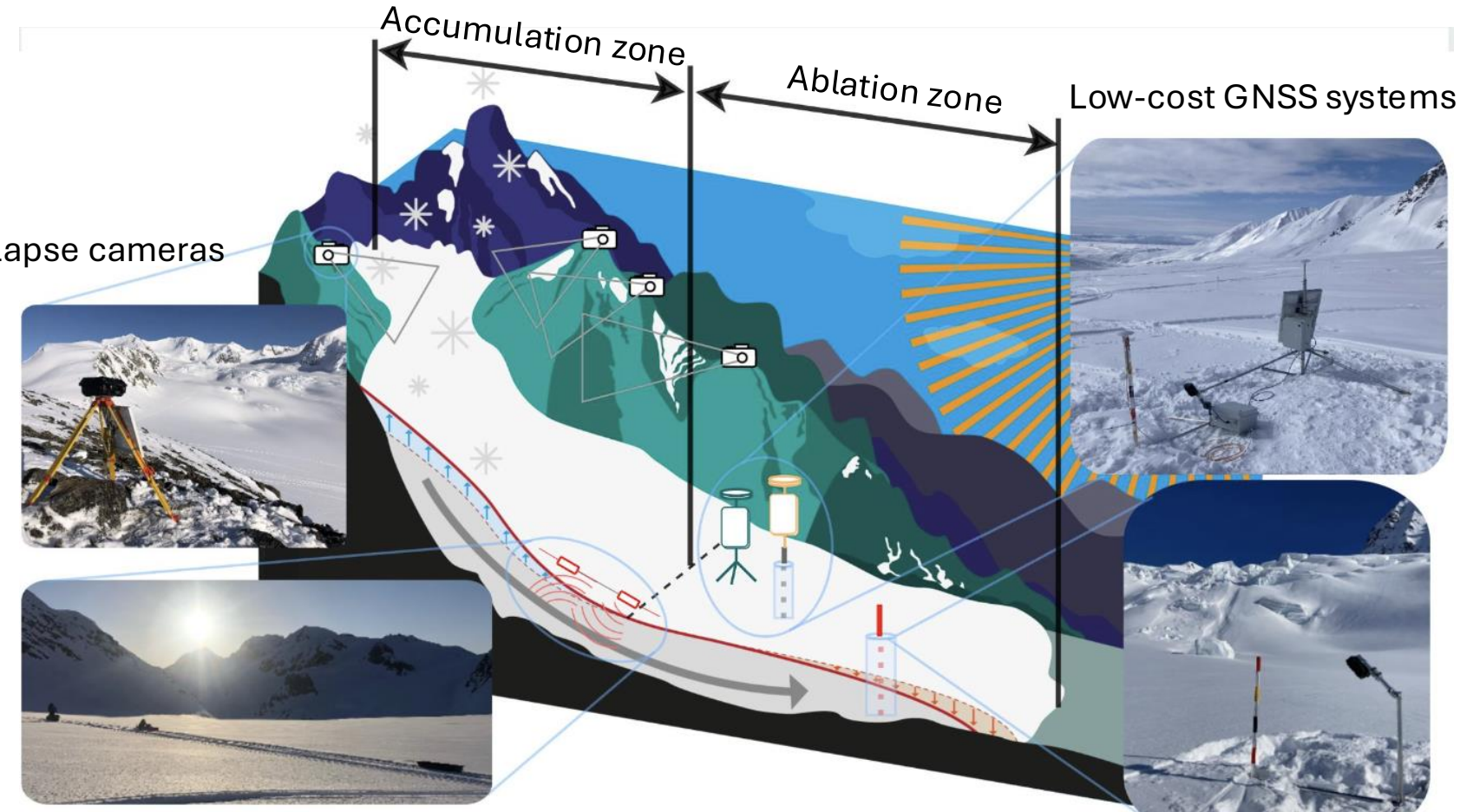
Improved model predicts *greater* disequilibrium in 2100 for both glaciers

Takeaways

- Historical images of remote Alaska are becoming publicly available
- Once digitally scanned, these images offer the potential to gain long-term insights of glaciers across Alaska
  - Mass balance, historical glacier volume, velocity and driving stress
- Multi-decadal mass balance records improve projections in the near (decade-scale) and distant future (century-scale)
  - By constraining glacier evolution over ~80 years, we have higher confidence in projections 80 years from now

- ***Such data/analyses ultimately enables us to anticipate future changes and develop strategies to mitigate the impacts on sea-level rise, ecosystems, water resources, and the communities that rely on these glaciers***

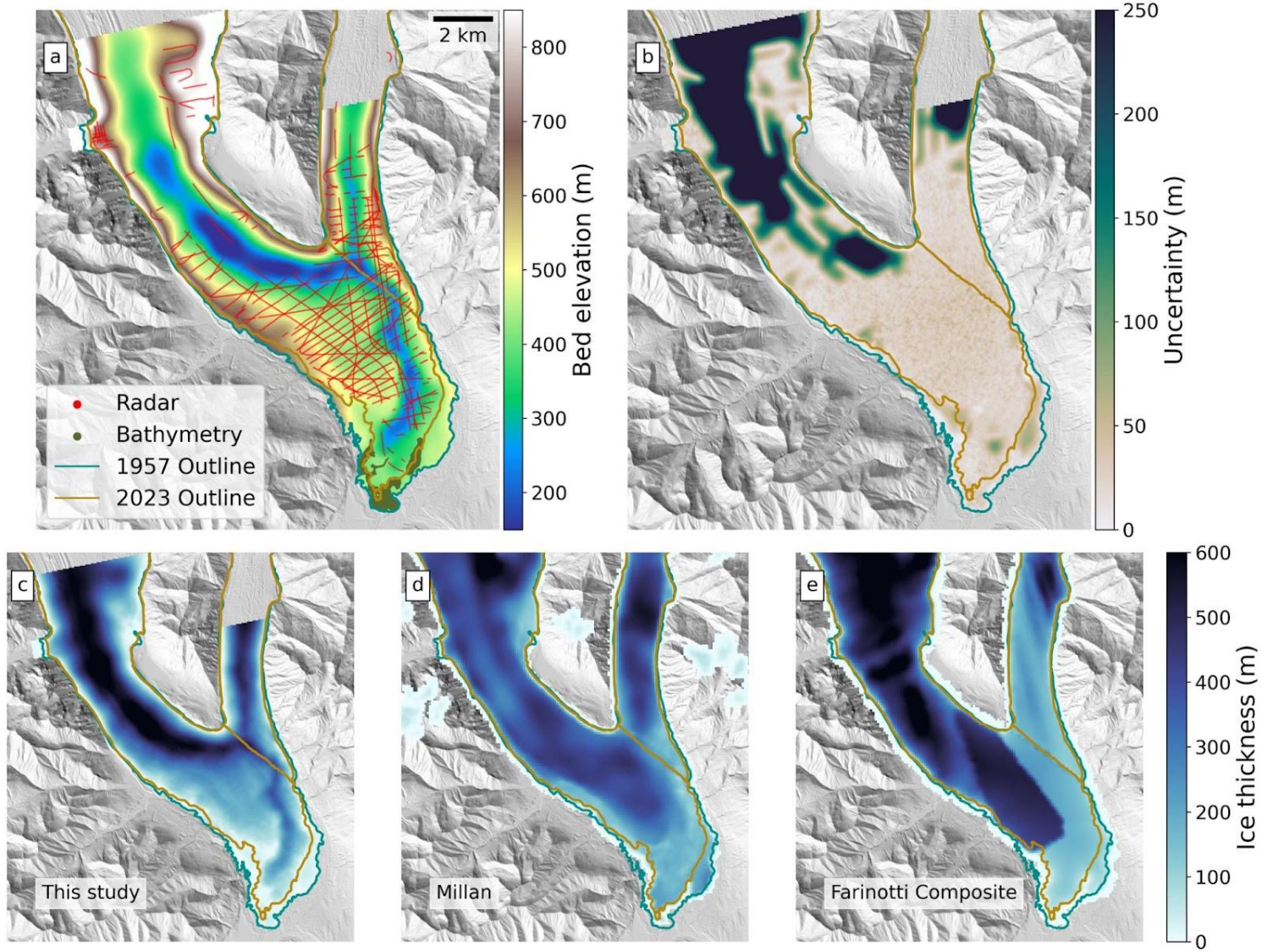
...some other projects I've also been working on...



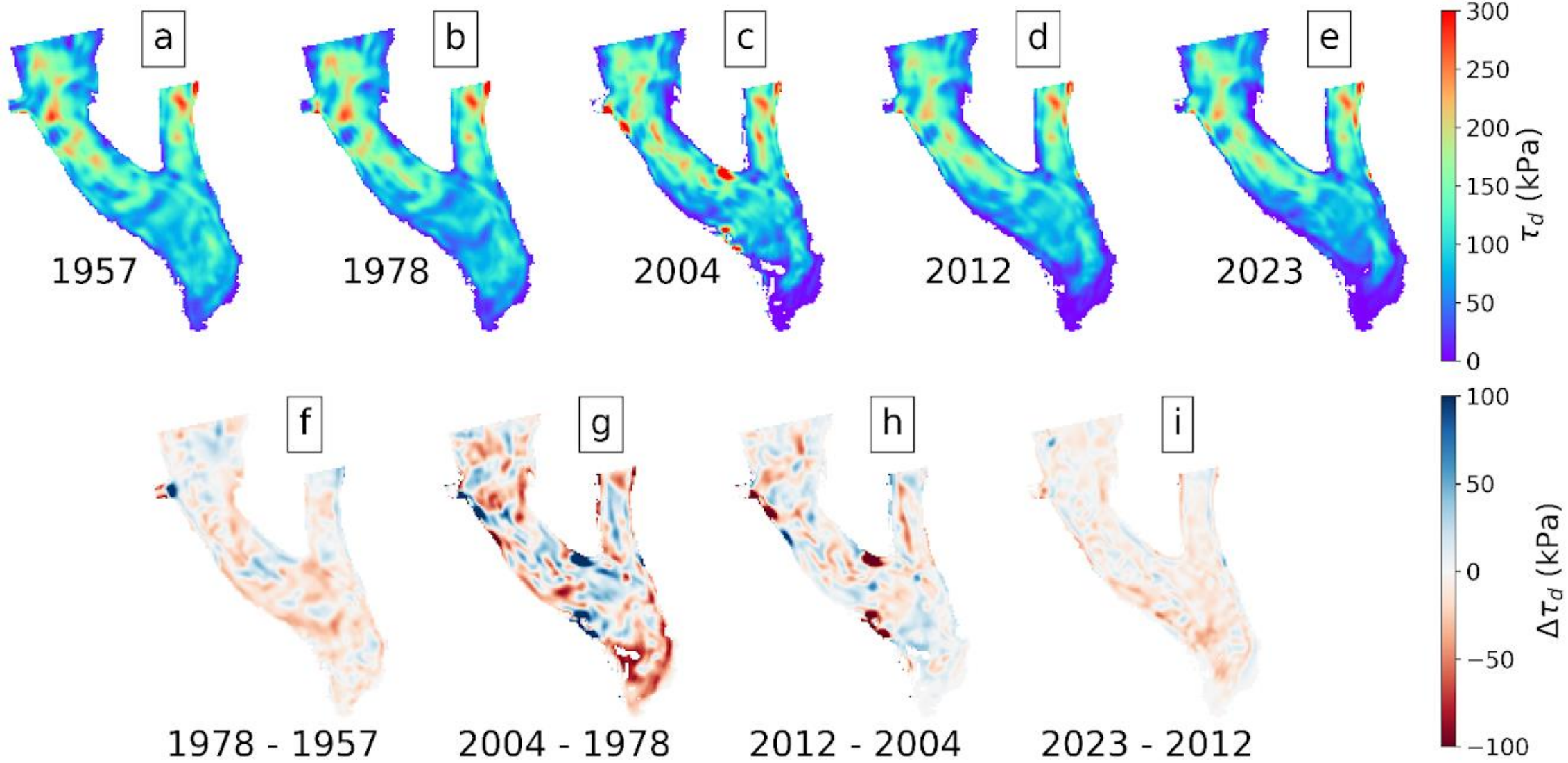
- Climatic mass balance (seasonal, daily, etc)
- Flux divergence (sub-seasonal)
- Field data vs. remote sensing vs. modeling

Credit: Bradford Washburn, 1938

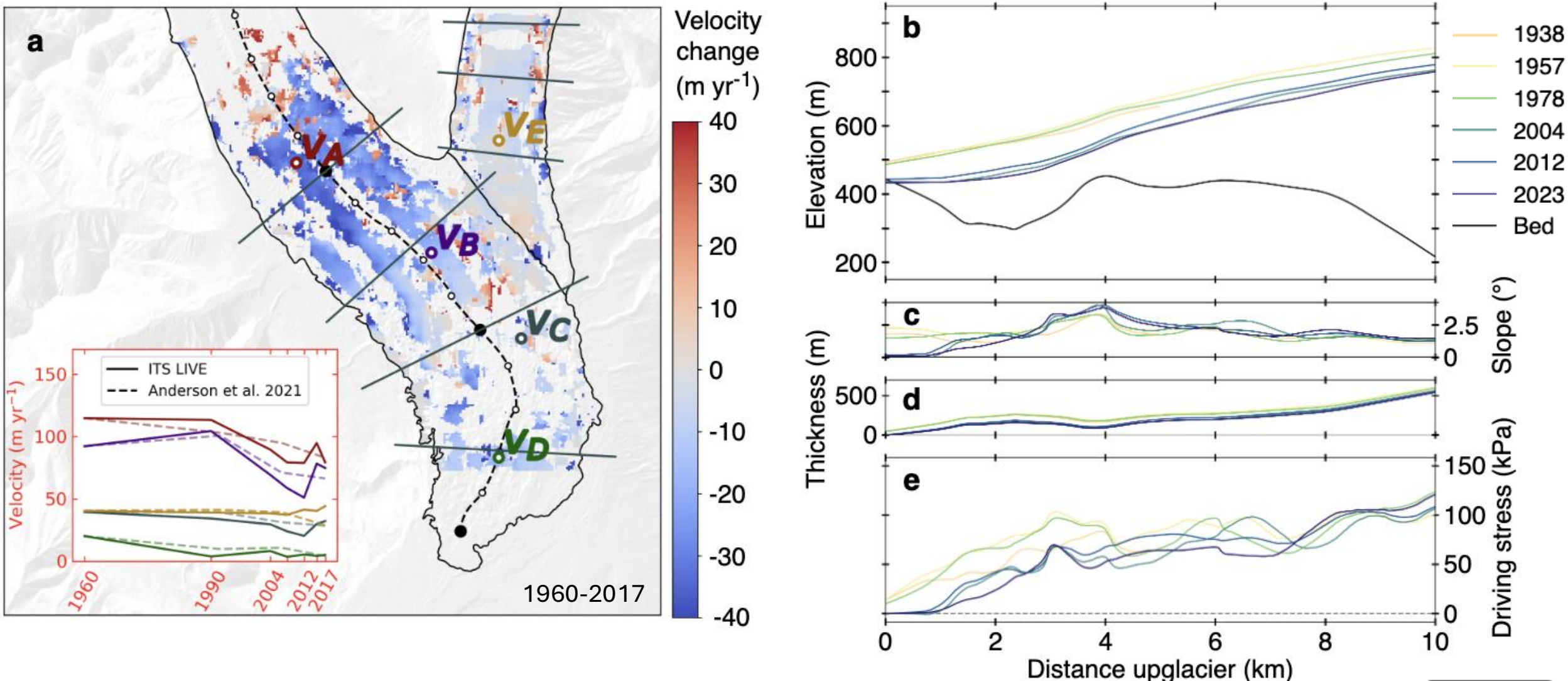
Bed data


a
2 km
Radar
Bathymetry
1957 Outline
2023 Outline
800
700
600
500
400
300
200
Bed elevation (m)
b
250
200
150
100
50
0
Uncertainty (m)
c
This study
d
Millan
e
Farinotti Composite
600
500
400
300
200
100
0
Ice thickness (m)

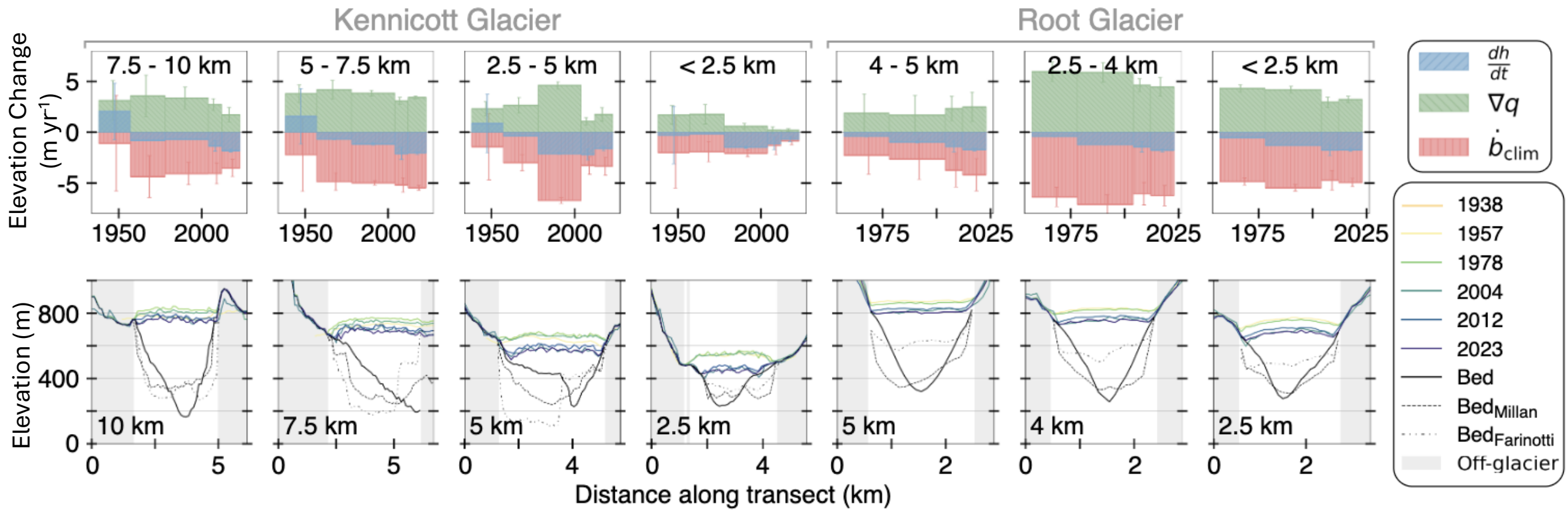
Spatially-distributed driving stress



Substantial changes in glacier dynamics over time

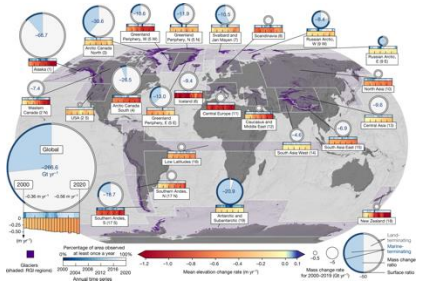


Glacier slowdown drives modern-day retreat on debris-covered terminus

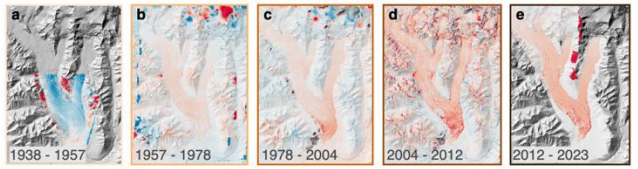


How do past observations change glacier evolution model projections?

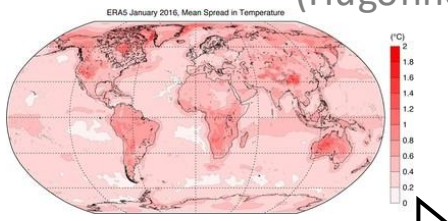
1. Calculate historical glacier volume & calibrate model with historical volume (~1940)
2. Run PyGEM from 1940-2023 for all plausible T_{bias}, k_p, and ddf_{snow} combinations
3. Select optimal parameter combinations
   - Match modeled mass balance to DEM differencing observations (within uncertainty)
   - Calculate RMSE misfit of elevation-binned change in ice thickness
   - n=89 for Kennicott Glacier, n=22 for Root Glacier
4. Run PyGEM to 2100 for all optimal parameter combinations
   - Take the mean of all simulations
   - Run projections for four emissions scenarios



2000 - 2020
(Hugonnet et al., 2021)



1938 – 2023



Climate data
(ERA5)

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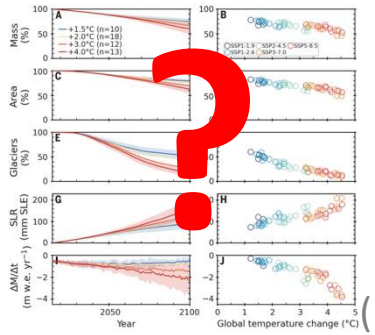
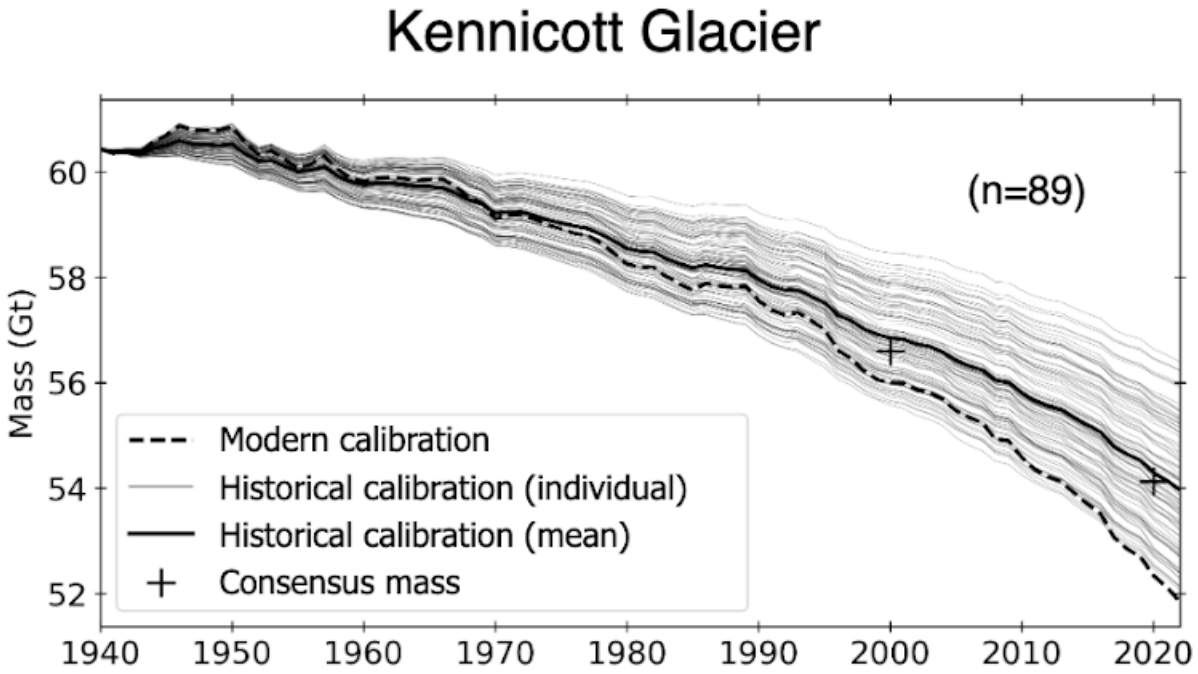
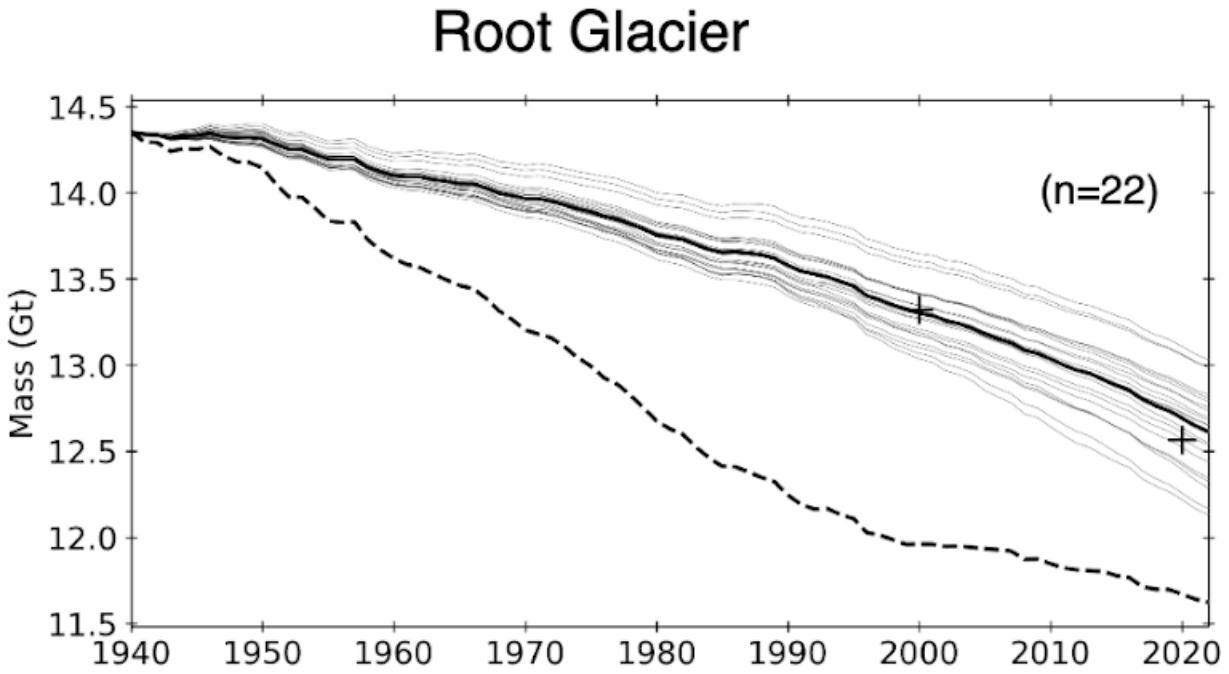


2020 - 2100
(Rounce et al., 2023)

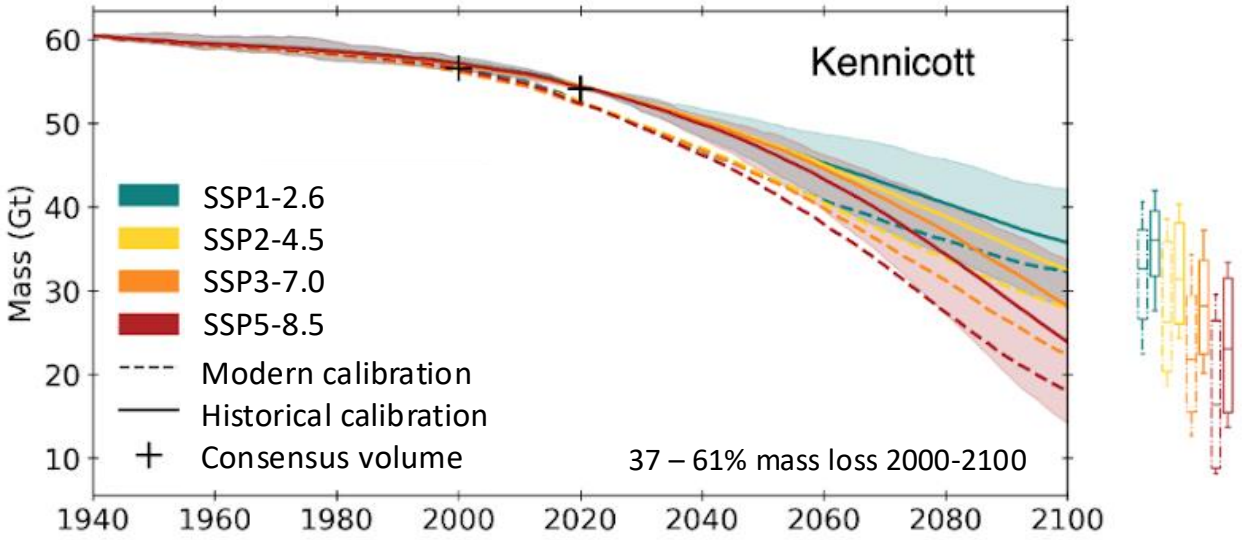
Historical mass balance enables glacier mass reconstruction from 1940-2023



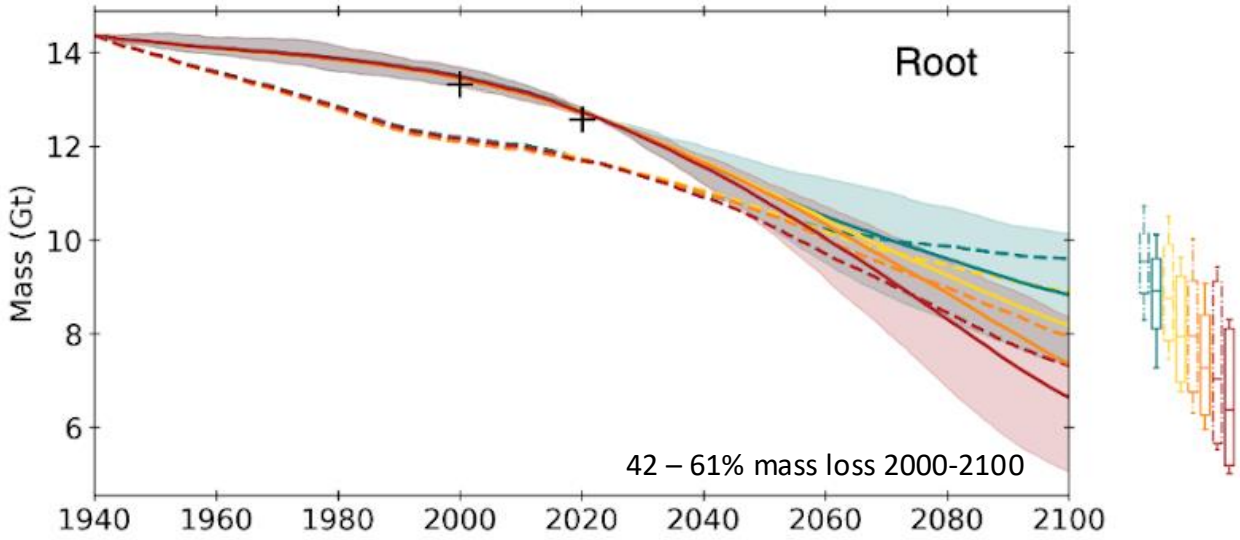


Past observations constrains future mass loss

Kennicott Glacier



Root Glacier



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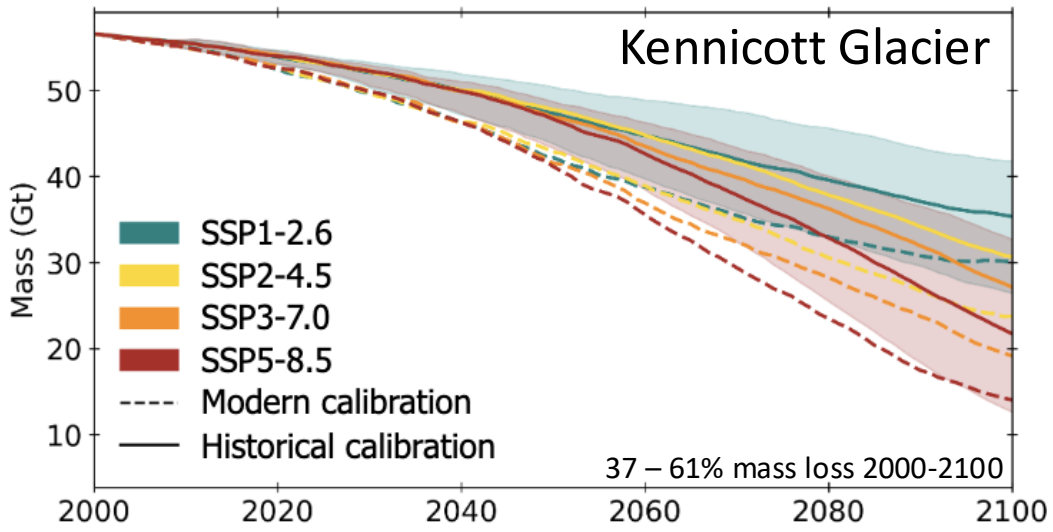
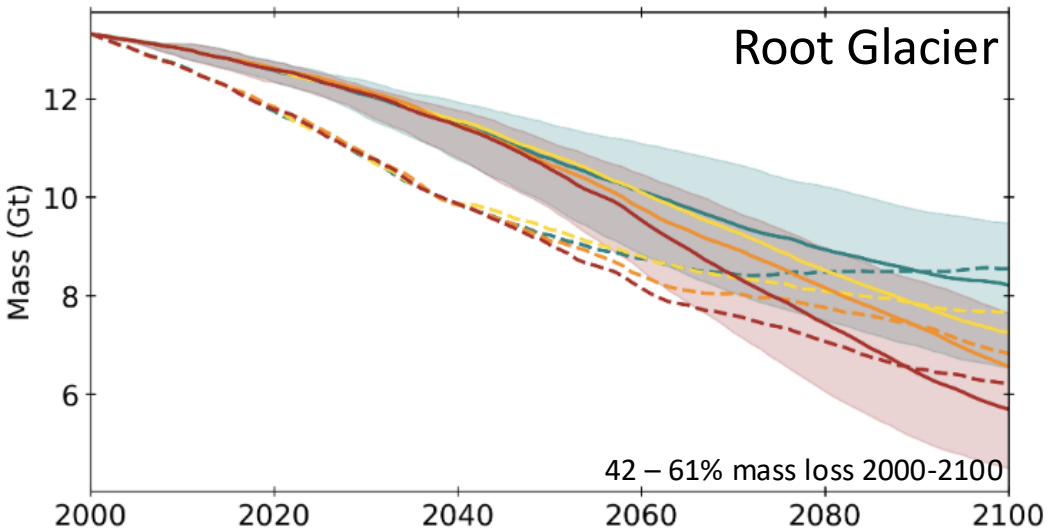
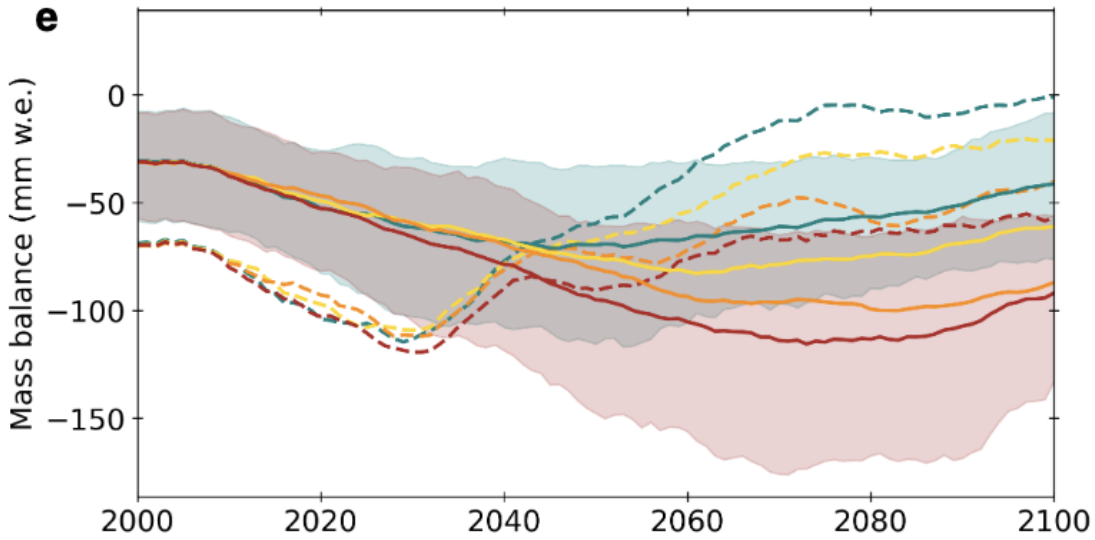
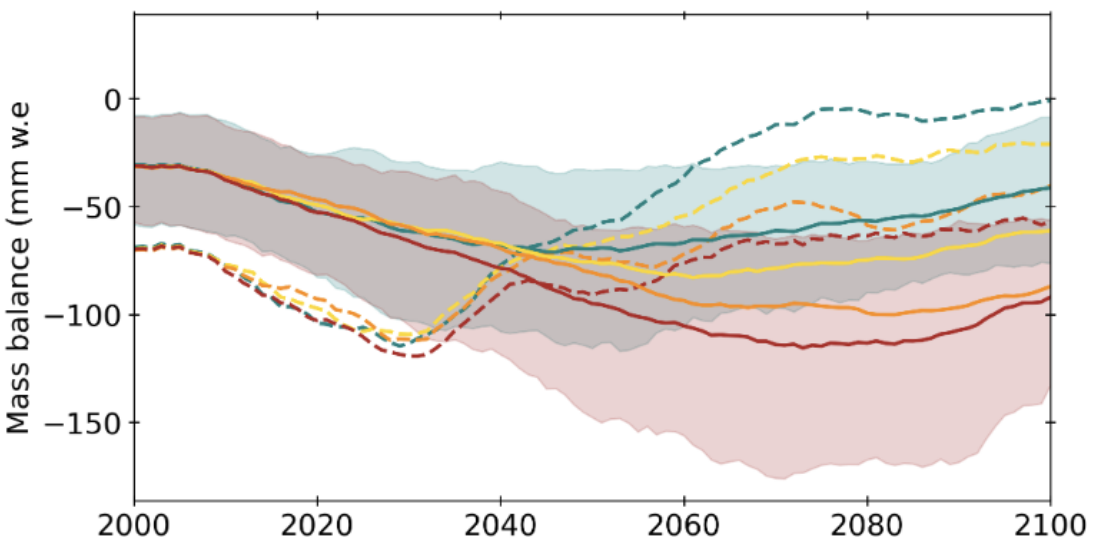
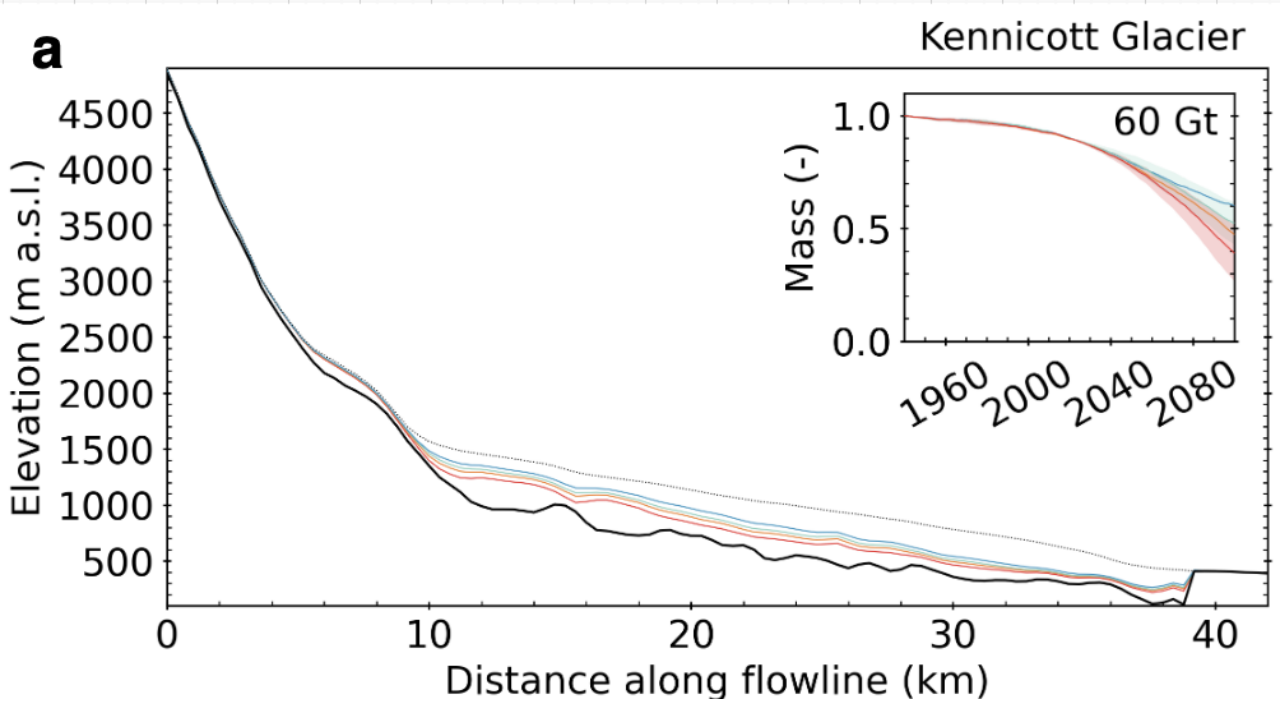


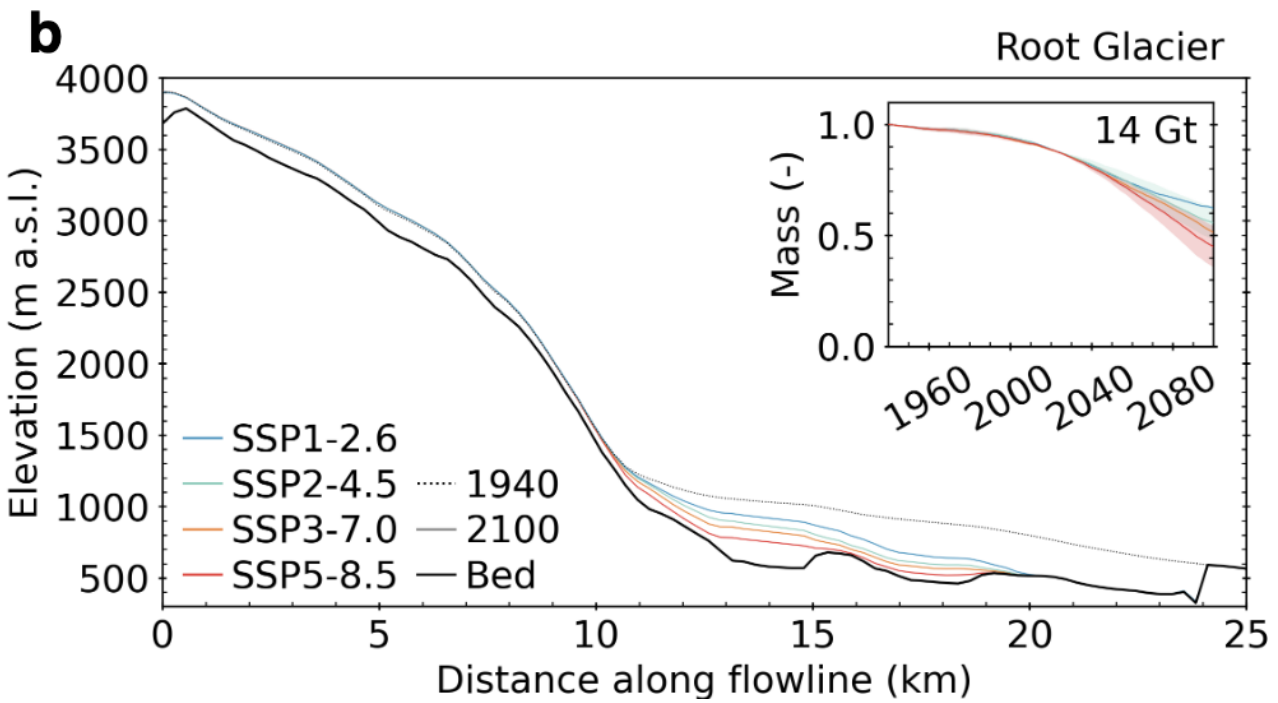




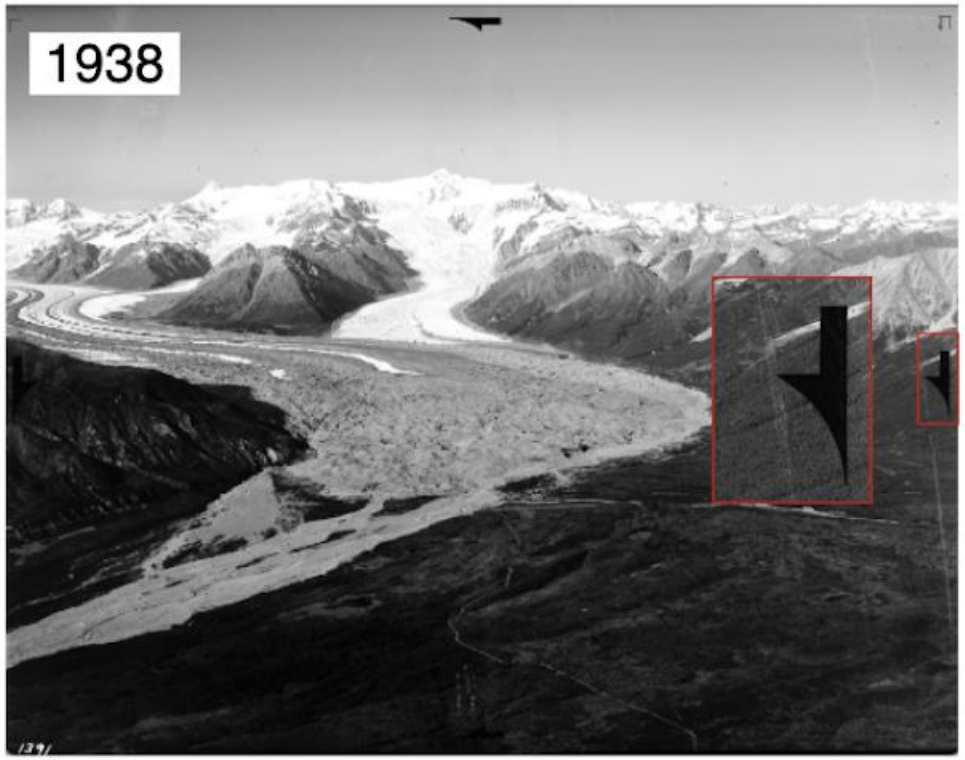


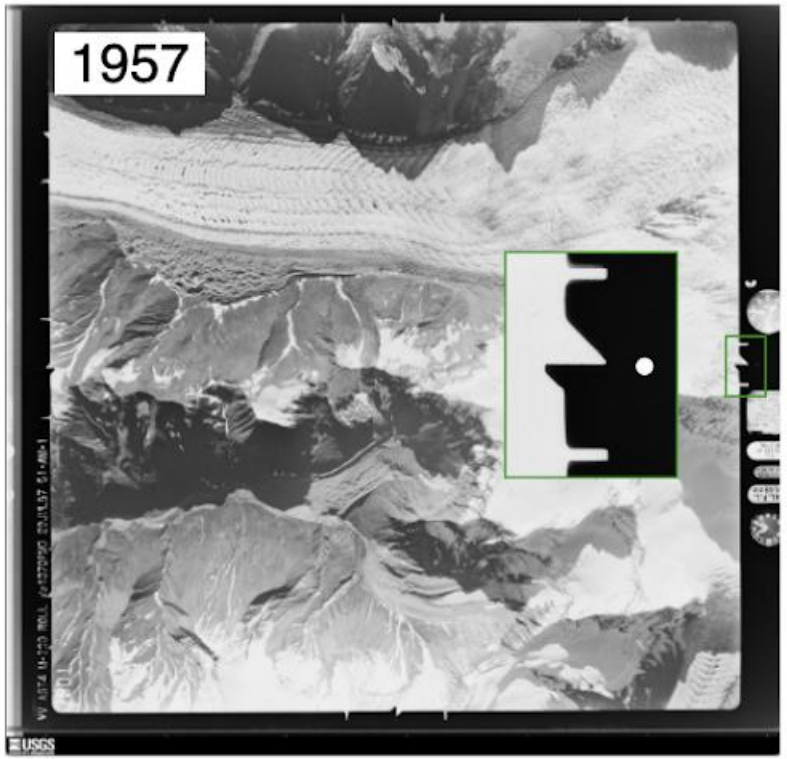
Modeled glacier change along centerline

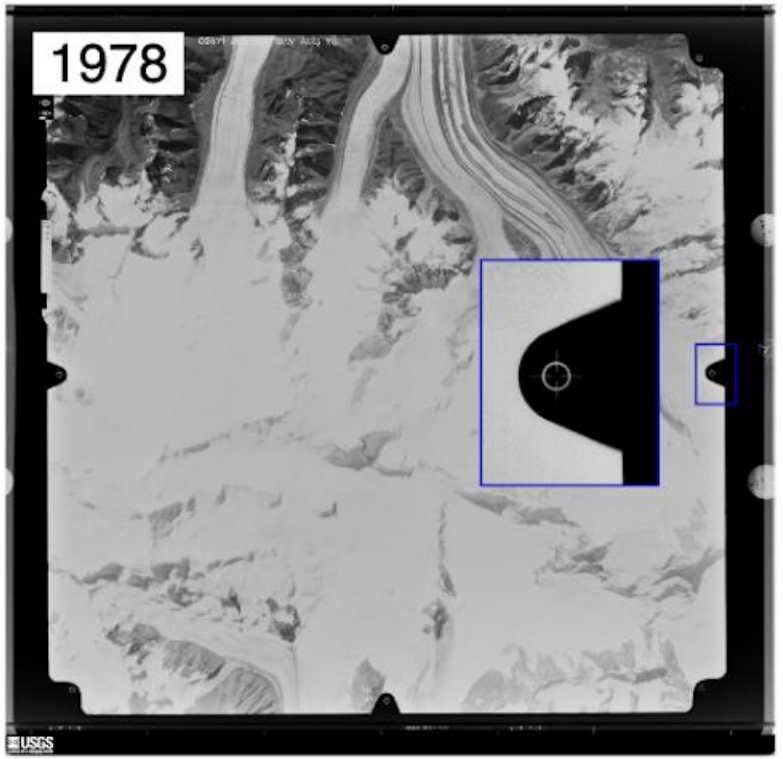




Example fiducial marks on film photographs



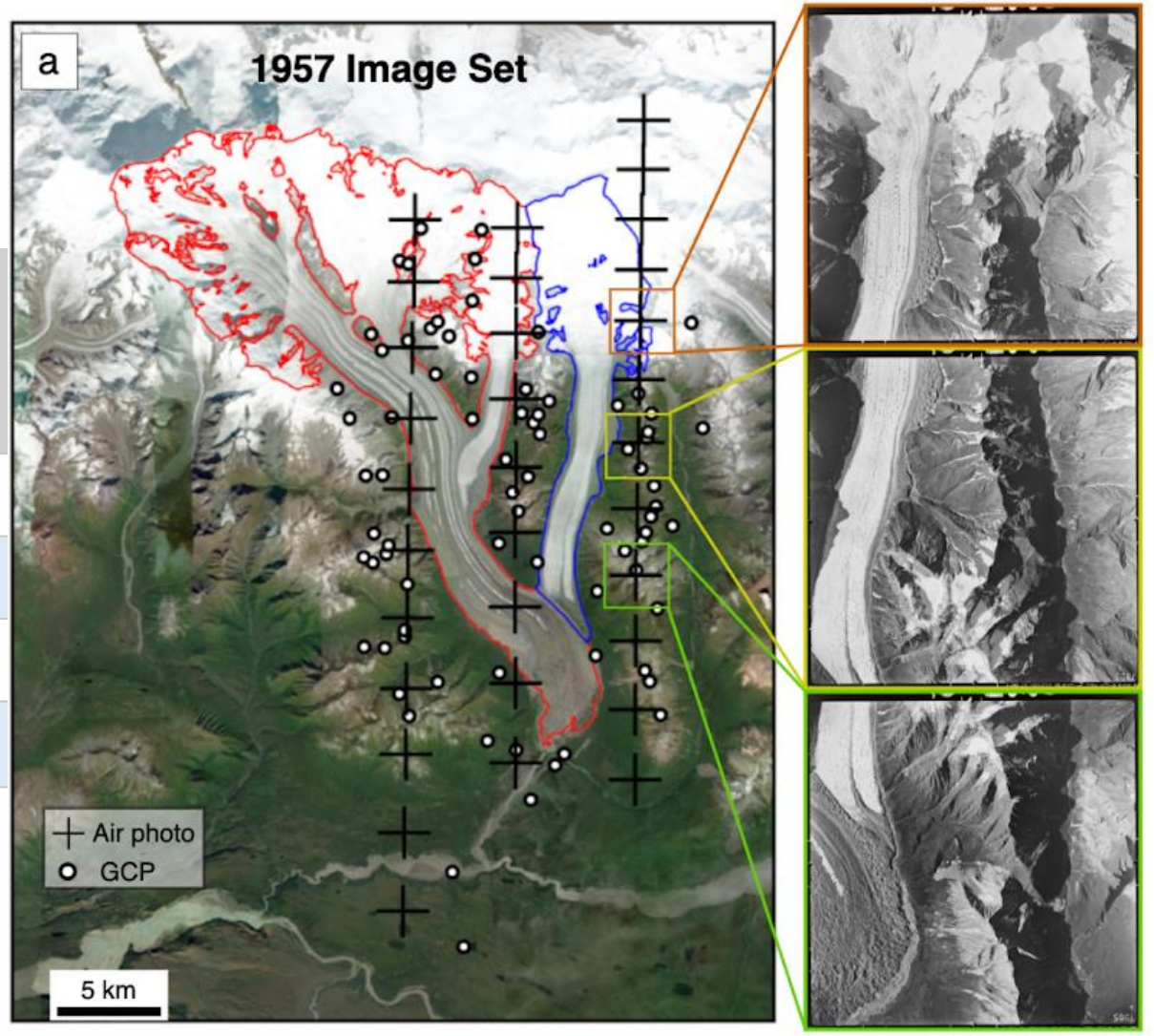




Historical aerial photographs enable glacier surface reconstruction

- We generate historical DEMs with high spatial resolution and accuracy using structure-from-motion photogrammetry

Year	Images used	GCPs	GCP error [m]	Dense cloud points [10^6]	DEM resolution [m]
1938	3	9	79.8	15.4	10
1957	32	77	3.21	47.3	4.53
1962	5	30	0.81	7.6	5.27
1978	17	81	1.04	12.6	12.6



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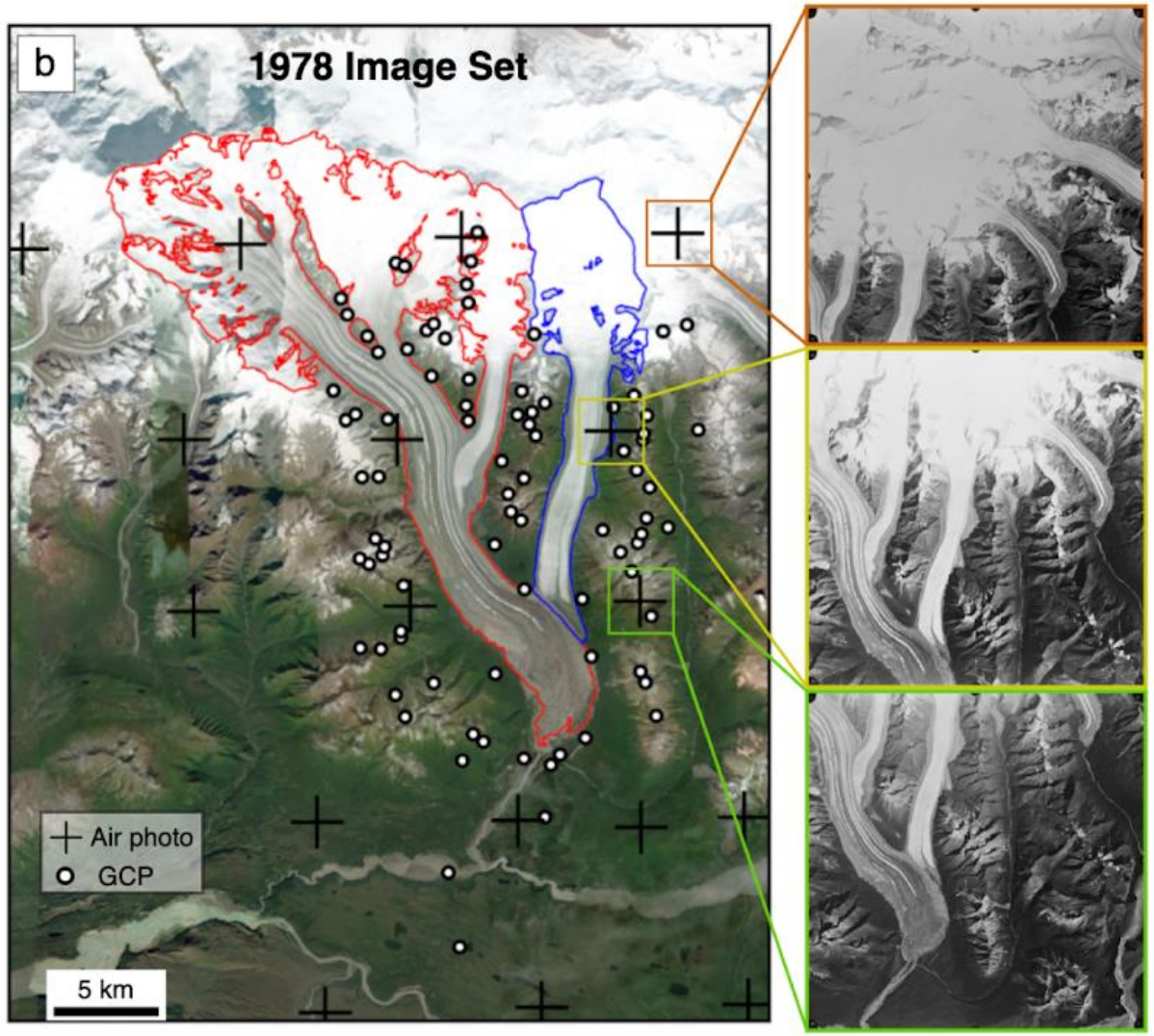
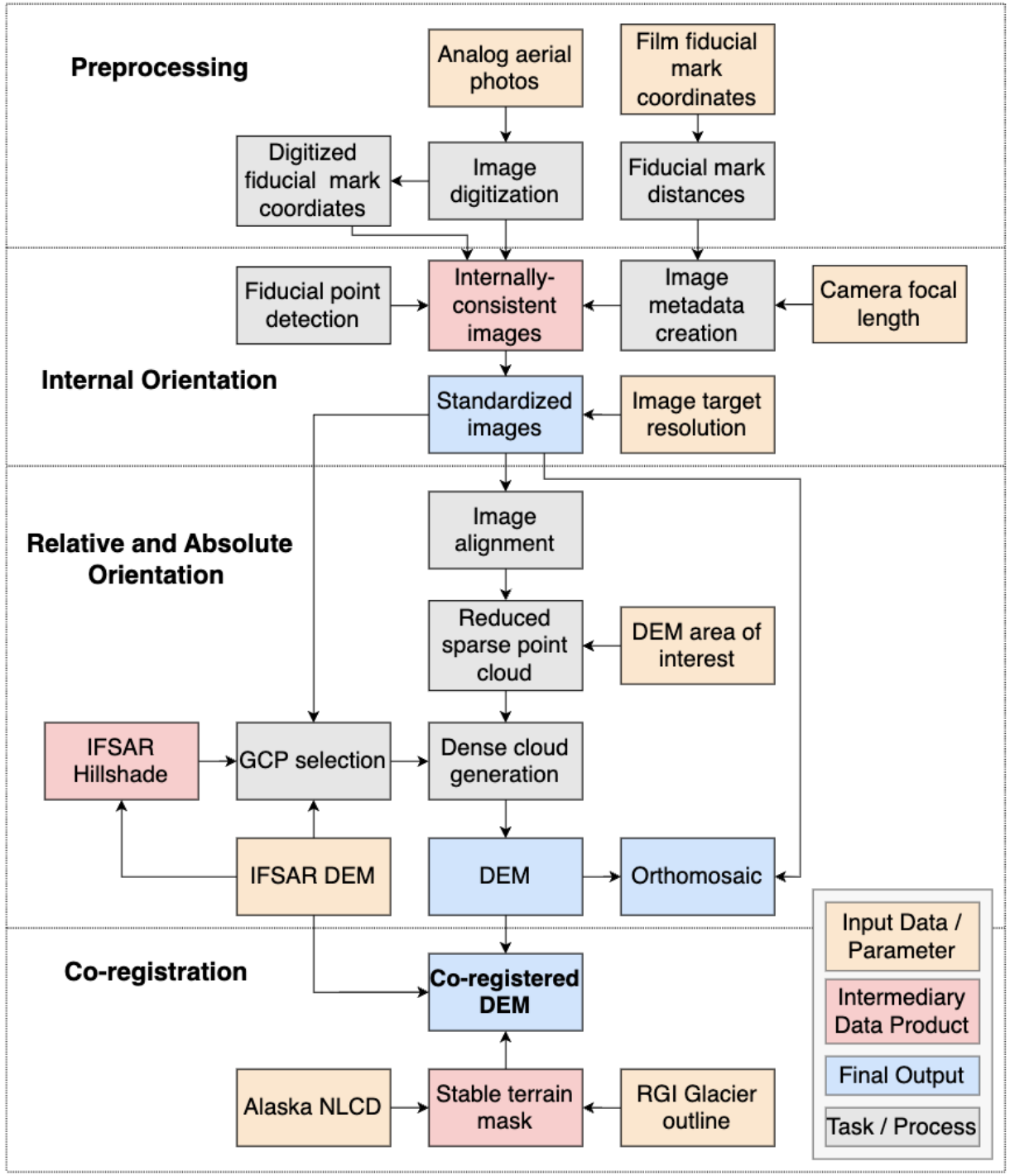
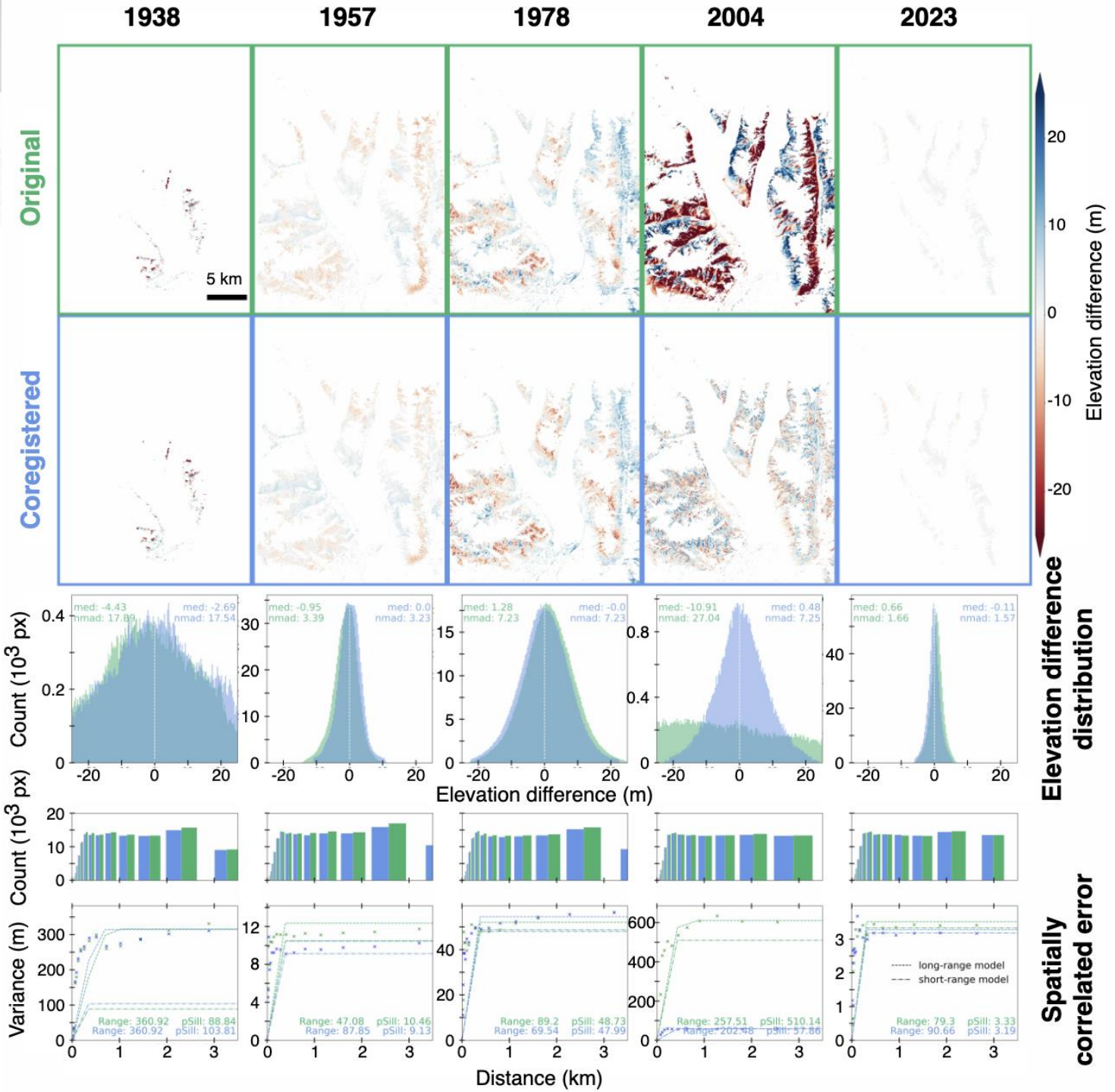


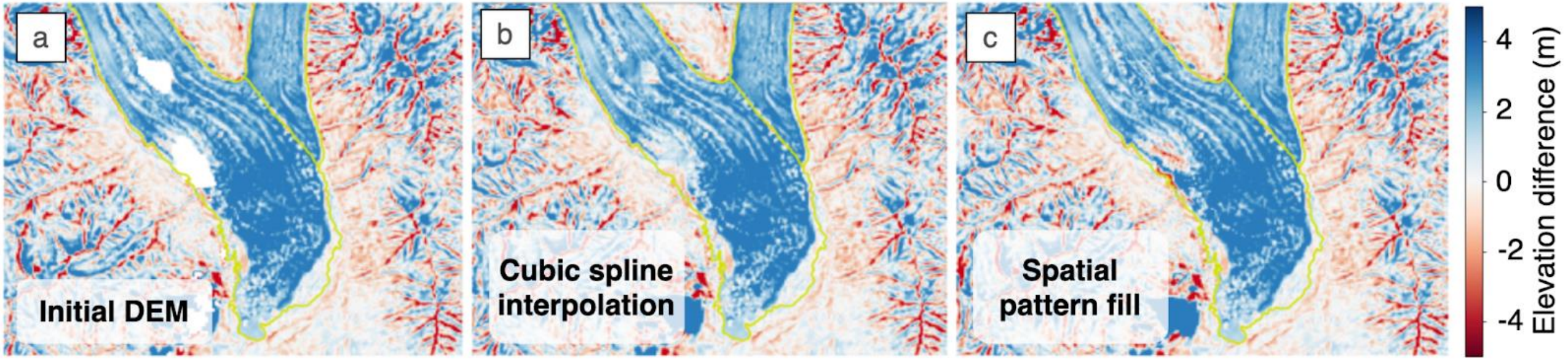
Historical DEM processing workflow



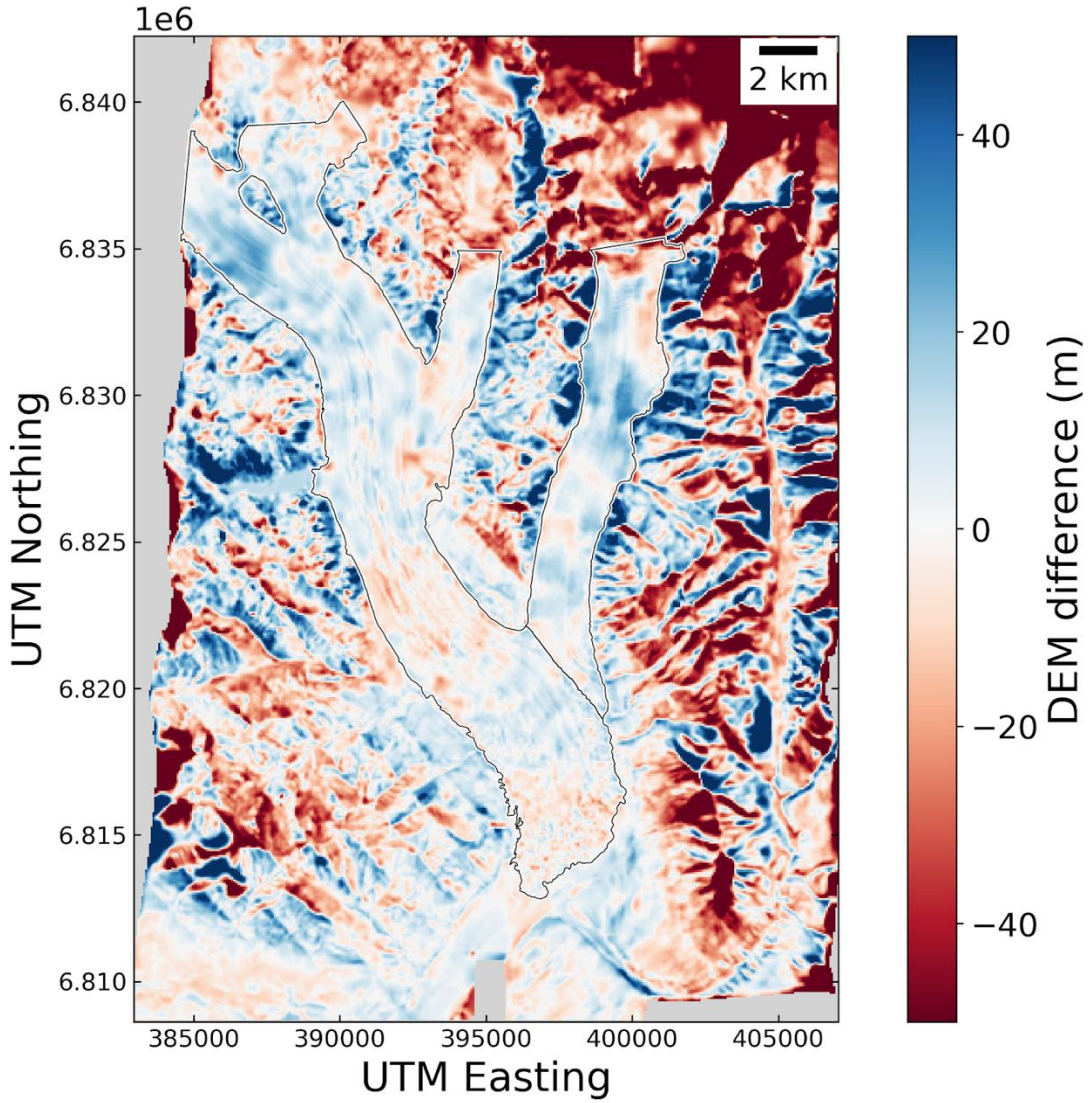
Historical DEM accuracy



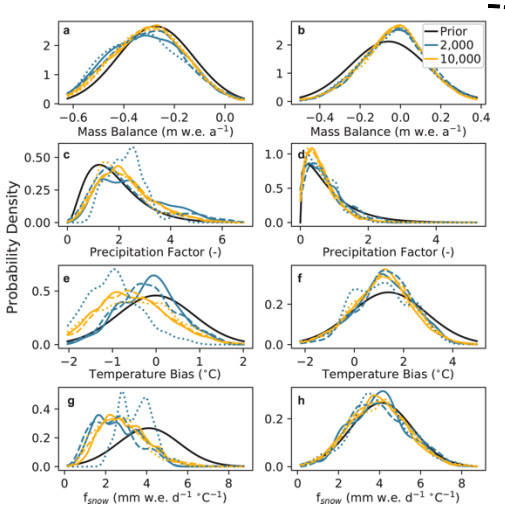
Comparison of DEM hole-filling techniques



Comparison between 1957 DEM and 1957 DEM derived from USGS topographic maps

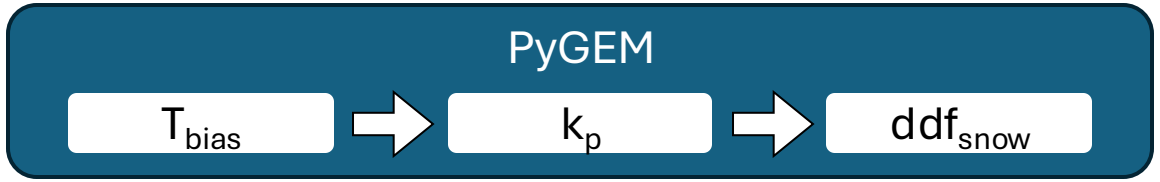


Step-wise calibration of PyGEM (future steps)

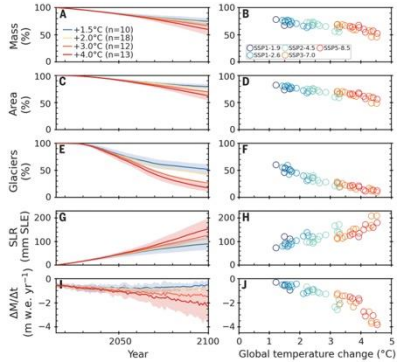


Parameter uncertainty

(Rounce et al., 2020)

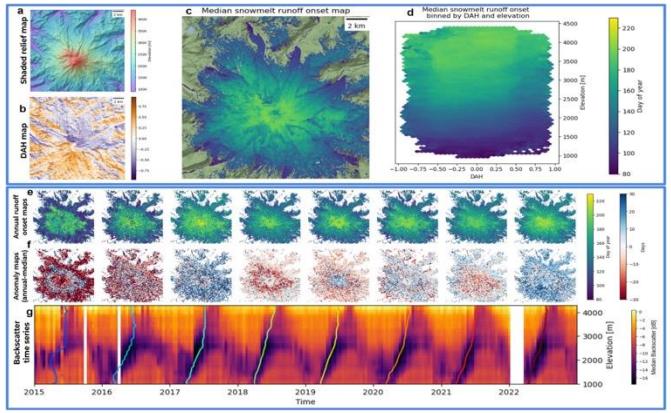


Improve projections



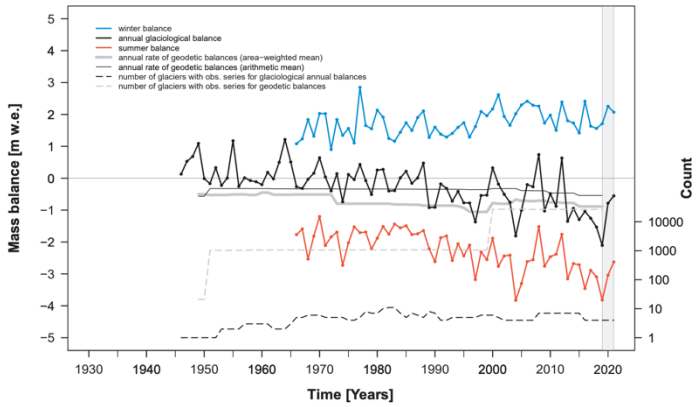
SAR melt extents

(e.g., Gagliano et al., 2023)



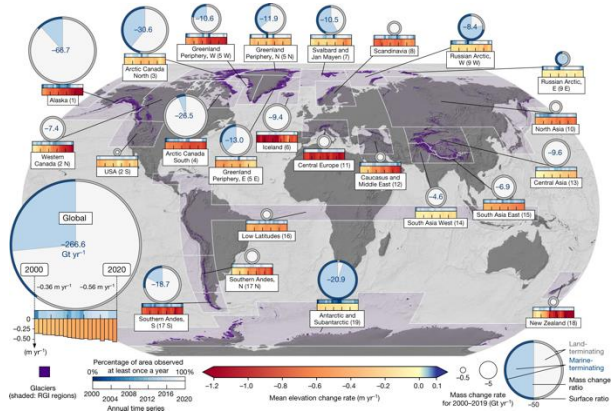
Winter mass balance

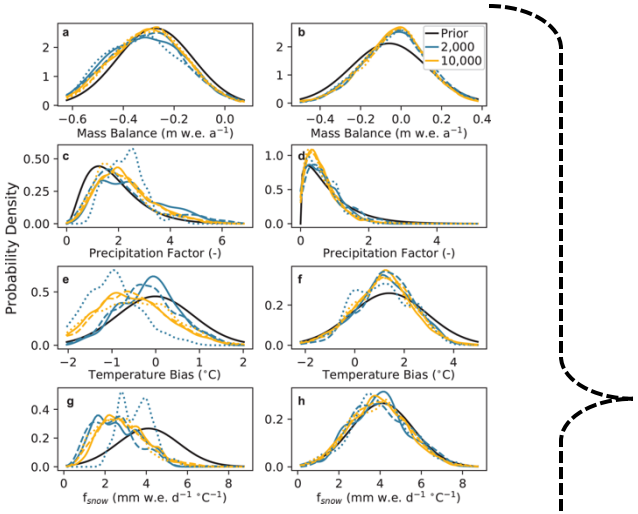
(e.g., WGMS, 2023)



Annual mass balance

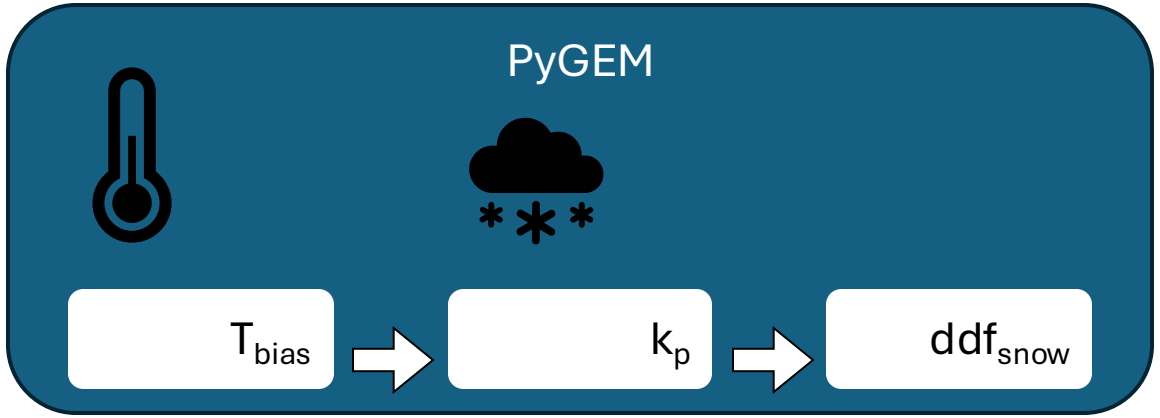
(e.g., Hugonnet et al., 2021)



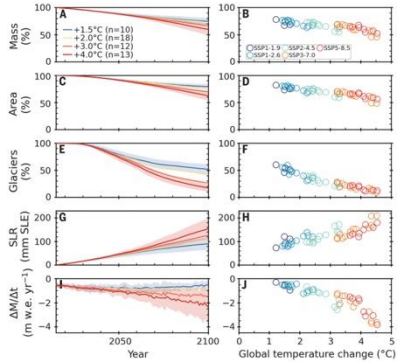


Parameter uncertainty

(Rounce et al., 2020)

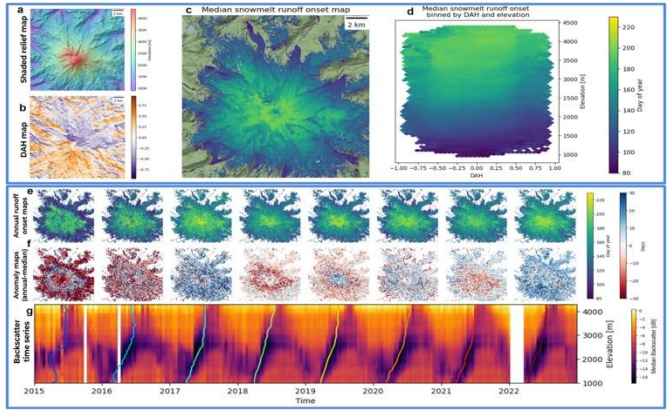


Improve projections



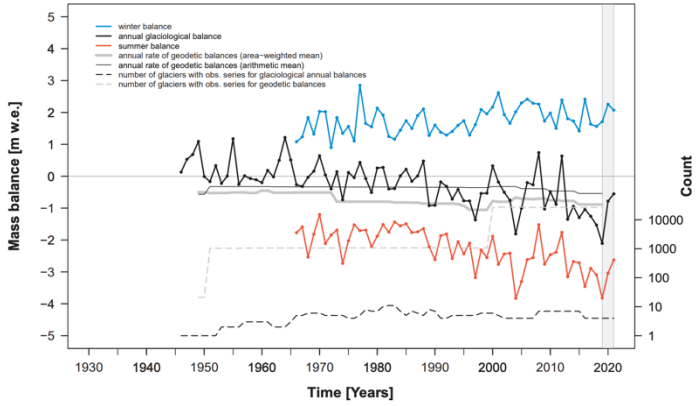
SAR melt extents

(e.g., Gagliano et al., 2023)



Winter mass balance

(e.g., WGMS, 2023)



Annual mass balance

(e.g., Hugonnet et al., 2021)